A PROPOSAL FOR

A NAVY TECHNOLOGICAL FORECAST

PART 2 - BACK-UP REPORT

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Headquarters, Naval Material Command
Department of the Navy
Washington, D.C.

Navy Technological Forecasting

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Part 1, Summary Report, presents in concise form the results of a six-month study carried out by the Navy Technological Forecasting Study Group. The preparation of a Navy Technological Forecast is recommended, the nature and utility of such an effort are described, and a procedure for its accomplishment is briefly presented.

Part 2, Back-Up Report, here presents much detailed supporting material, sample forecasts, methodologies, and possible categories. It is expected that the details covered will greatly aid those responsible for generating Navy Technological Forecasts.

The following pages—taken from enclosed sample forecast material—are omitted from this printing in order to provide an unclassified version of this document: Pages 3-18, 3-22, 3-23, 4-15 through 4-19, 5-5, 5-6, 5-7, 6-4 through 6-7, 7-2, 7-3, and 7-4.

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CHAPTER 1

INTRODUCTION

A technological forecast describes scientific knowledge, technical capabilities, and examples of systems, subsystems, and components which science and technology can be expected to produce over a specified time if supported by orderly programs of research and development. A meaningful forecast of science and technology as far as twenty years into the future will help better to estimate enemy technical capabilities in that time frame and to project in more explicit terms the enemy threat which the Navy and Marine Corps may encounter. In addition, a good forecast will help make possible the prediction of improved and radically new operational capabilities in support of offensive and defensive naval missions, as well as assist in the coordination, on a Navy-wide basis, of the current and future efforts in research, exploratory development, and advanced development. A quality forecast is a prerequisite to successful short- and long-range planning.

Although forecasting is necessarily a part of the Navy's everyday operations, it is currently done in a fragmentary manner. Technological forecasting as a science is very new, and no formal approach to forecasting methodology has been developed.

Section 1. BACKGROUND

Following several informal meetings of representatives of the Chief of Naval Operations (CNO), the Chief of Naval Development (CND), the Chief of Naval Research (CNR), and the Navy technical bureaus, a formal Technological Forecasting Steering Committee was established by CND with representatives from the Office of Naval Research (ONR), the Bureau of Ships (BUSHIPS), and the Bureau of Naval Weapons (BUWEPS), who, at a meeting on 11 February 1965, recommended that a study be made to determine the feasibility and utility of a Navy Technological Forecast (NTF).

In its report,* the ad hoc study group, drawn from the technical bureaus and from five Navy laboratories in the Washington area, concluded that the Navy would realize definite benefits at all management levels from application of technological forecasts to research planning, systems development, and operational decision-making.

The study disclosed the existence of forecasting by other government agencies and industry. Of prime interest to the Navy was the Air Force's "Project Forecast" conducted in 1963, and the Army's continuing "Long Range Technological Forecast" initiated in 1962. Both of these forecasting efforts are used extensively as guides in the respective Air Force and Army long-range planning programs. Similarly, several industrial concerns use forecasting in their R&D planning.

A technological forecast is defined as "the prediction, with a level of confidence, of a technical achievement, in a given time frame with a specified level of support." A technological forecast is a tool for planning and decision-making; it is not a plan. Each achievement predicted will provide one segment of the integrated information required for directing technology toward operational needs, for defining operational capabilities which would follow on scientific advances, for the early selection and support of promising areas in science and technology, for assessing the probable progress and success of a program, and for the optimum utilization of resources. A technological forecast will make more effective the Navy technical community's capability to project technological advances in the development of new capabilities for the operating forces. The forecast, by indicating technical capabilities, could influence changes

*Study by Ad Hoc Group on Navy Technological Forecasting," 15 June 1965.

in strategies and tactics, could promote development of innovative operational techniques, and could aid in satisfying stated operational requirements.

The recommendations of this study were accepted by the Chiefs of Naval Development and Naval Research, and by the Assistant Secretary of the Navy for Research and Development [ASN(R&D)], who requested that planning for the implementation of the forecasting program be initiated.

Section 2. OBJECTIVE

A group consisting of one member from each of five in-house Navy laboratories, operating within the mission of the Advanced Concepts Branch of the Exploratory Development Division, Headquarters, Naval Material Command (formerly Office of Naval Material), was formed with a mission to formulate a plan for a Navy technological forecast. The Navy Technological Forecasting Study Group was convened on 1 November 1965 for a period of six months.

The major objectives of this Group were:

a. To study in greater detail the methods and techniques of forecasting employed by the Army, Air Force, and Marine Corps, as well as those of other government agencies and industrial companies, with reference to their application to the proposed Navy Technological Forecast,

b. To develop a method to implement the Navy Technological Forecast to encompass the work now being conducted and projected for execution under the Navy's RDT&E programs,

c. To identify the scientific and technical input requirements of management personnel which would be required for a meaningful forecast,

d. To design the overall structure of the forecast, the format of individual forecasts, and methods of generation, review, and publication of forecasts,

e. To explore the several available forecasting methodologies in terms of their use in preparing Navy Technological Forecasts,

f. To consider the implications of interservice forecasting.

CHAPTER 2

APPLICATION AND UTILITY OF TECHNOLOGICAL FORECASTING

Section 1. THE PROPOSED NAVY TECHNOLOGICAL FORECAST

In the course of its study the Navy Technological Forecasting Study Group surveyed the methods and techniques of forecasting employed by the Army, Air Force, Marine Corps, other government agencies, and industrial corporations. The forecasting efforts of the Army, Air Force, and Marine Corps are described in Sections 4, 5, and 6, respectively, of this chapter.

On the basis of this study it is proposed that the Navy Technological Forecasting Program should employ two complementary approaches:

a. Basic Forecast

Part I - Scientific Opportunities
Part II - Technological Capabilities
Part III - Probable Systems Options

b. Technology Needs Identification Studies (TENIS).

Part I (Scientific Opportunities) should include all research in the physical, engineering, environmental, and life sciences, conducted under RDT&E category 6.1. The opportunities and limitations in both nonmaterial and material-oriented research which are relevant to future technical capabilities of the Navy and to scientific advance should be discussed. This section of the forecast is described in detail in Chapter 4.

Part II (Technological Capabilities) should include that part of applied research and development which is normally referred to as exploratory development (category 6.2). It should cover a broad spectrum of research and development ranging from the basic technologies to functional subsystems which are foreseen to be achievable in areas vital to the attainment of naval technological goals. This section of the forecast is described in detail in Chapter 5.

Part III (Probable Systems Options) would include examples of systems which might be provided if the capabilities described in Part II were achieved. The examples should be brief descriptions of such system concepts. Each description should be supported by a technical report which describes the proposed system concept in terms of parametric characteristics which are derived from an analysis of the several subsystem and components involved in the concept. This section of the forecast is described in detail in Chapter 6.

The second proposed approach to the forecast is a series of Technology Needs Identification Studies which are similar in general outline to the Technical Workshops, but with the prime purpose being the identification of critical technology areas. While this TENIS approach is essentially a planning procedure designed to fulfill specific needs, it provides a valuable insight into supporting RDT&E capabilities and deficiencies. In each study, mission needs which are identified by cognizant authority and translated into associated functional capabilities and corresponding technical requirements are forecast in detail. These forecasts-in-depth are based on a projection of the expected technological developments and applications during the forecast period and are conducted prior to the Workshop. The Workshops would also utilize the principal technological forecast information that applies to that specific area. System design parameters are defined and an analysis is made of the supporting research and development effort required to achieve the operational objectives. This approach to the forecast is described in detail in Chapter 7.

Methods of implementing the proposed Navy Technological Forecast are discussed in Chapter 8.

Section 2. APPLICATION TO THE NAVY RDT&E PROGRAM

RDT&E planning within the Department of the Navy is characteristically conducted as a dialogue between the "User Interest," represented by the Chief of Naval Operations and the Commandant of the Marine Corps as spokesmen for the Operating Forces, and the "Producer Interest," represented by the Chief of Naval Material in speaking for the entire Naval Material Command (NMC). Final plans are the result of "negotiation" between the two interests. The planning process is one continuing iterative interchange. Through this process trade-offs should be made which will result in the maximum military capability for the Operating Forces that are possible within the limits of the resources available to the Naval Establishment.

If the Navy is to meet its operational needs in the future, early decisions are vital; it takes an average of eight years to get today's technical developments into the fleet. One element on which the necessary dialogue can be structured is a technological forecast, in which the Navy's technical community identifies future opportunities arising from advances in science as well as capabilities which future technological developments will provide.

A meaningful forecast will assist in the projection of military policy and force structures to meet anticipated enemy threats. It would find extensive use in:

a. Projecting U.S. technological capabilities during the forecast period. It would identify advanced technologies which would permit development of systems to enhance the operational capability and effectiveness of the Navy.

b. Providing the necessary input into a technology/capability matrix to define Exploratory Development Goals and systems configurations to meet or exceed the projected enemy threat. Scientific and technological areas which, intuitively, appear to have high pay-off not directly responsive to the projected threat would be identified.

c. Making better postulations of the enemy threat during the forecast period by identifying U.S. technological capabilities which may be assumed to be within an enemy's potential. Complete interpretation, understanding, and dissemination of the threat are considered to be outside the scope of the forecast.

d. Serving senior management by presenting strengths and capabilities of Navy's scientific and technical efforts.

By formalizing the inputs from the technical community to the definition of long-range military capabilities, the forecast could be used in preparing the following planning documents:

a. Navy Long Range Strategic Study (NLRSS),

b. Navy Mid-Range Study (NMS),

c. Navy Mid-Range Objectives (NMRO),

d. General Operational Requirements (GOR),

e. Exploratory Development Goals (EDG),

f. Tentative Specific Operational Requirements (TSOR),

g. Advanced Development Objectives (ADO),

h. Specific Operational Requirements (SOR).

A formal forecast would provide inputs to feasibility studies at all levels in the Navy's intelligence operational and technical communities. The forecast would make available to the laboratories and technical offices projections of the state-of-the-art in supporting areas outside their immediate scientific or technical expertise. It would identify technological areas which have high potential in sensitive development areas. A moderate improvement in some technical areas, for example, can have a high impact on operational effectiveness, whereas a large technical gain in other areas may not improve an operational capability. It would also identify the extent of interdependence of the various technical disciplines and areas in which component developments are compatible or augment one another. When more than one function contributes to an end-item development, a reasonable forecast can be employed to determine the relative burden on the projected state-of-the-art in each contributing area. Hence, the projected forecast would be valuable in preparing Proposed Technical Approaches (PTA) and Technical Development Plans (TDP).

The generation of the proposed Navy Technological Forecast (NTF) would be the responsibility, primarily, of the various in-house laboratories. It is anticipated that in its preparation attention would be directed, not to linear extrapolation of current programs, but to all military areas of scientific and technical expertise.

The NTF, being generated by laboratory personnel, would strengthen the laboratories' planning functions by encouraging longer-range projections of scientific and technical capabilities and would provide greater communication with higher-echelon planners. Fluctuations in program planning and funding can be reduced by having better predictions which would improve operational capabilities based on anticipated advances in technology.

The NTF would stimulate an increased dialogue among the members of the Navy's technical community. The cross-fertilization by workers in the various areas of science and technology will tend to improve each participant's technical competence.

The NTF would also provide a means of recording new technological concepts which may not have immediate end-use but would have potential at a later date.

Each of Chapters 4, 5, 6, and 7 herein is addressed to the particular group that develops that section of the NTF. As a result there is some redundancy in the text of these sections.

Section 3. UTILITY OF THE PROPOSED NAVY FORECAST

Specific comments on the utility of the proposed NTF were made by representatives of the Chief of Naval Operations, the Marine Corps, the Naval Material Command, the Ship Systems Command (formerly BUSHIPS), and Ordnance Systems Command (formerly Part of BUWEPS). These are summarized as follows:

a. SOURCE: CNO (OP-093) RADM G. H. Miller, Director, Long Range Objectives Group, letter dated 1 March 1966

"The proposed forecast will identify the current and expected levels of capability for each area of technology. It will also identify alternate combinations of technologies applicable to future naval systems, as well as levels of future capability that can be expected to derive from these technological expectations. As a technical appraisal of the present and projected 'state-of-the-art,' the proposed forecast should provide a much better understanding of the feasibility of particular objectives and of the time frame in which they may be realized. Not only will this information be pertinent to the Navy Long Range Strategic Study (NLRSS), it will also serve in the development of Navy Mid-Range Objectives (MRO) which include quantitative statements of force levels in a period 10 to 15 years in the future. The availability of possible system concepts will permit refined statements of task requirements and force level objectives which are not now achievable. The forecast may make it possible for the MRO to be more specific in the establishment of objectives in terms of systems. Of singular importance would be the availability in a single source of data now often difficult to obtain or whose adequacy may be questioned.

b. SOURCE: BGEN E. E. Anderson, Deputy Chief of Staff, RD&S, Marine Corps letter dated 2 March 1966

"A Navy Department technological forecast embracing the scientific and technical areas of interest of both the Navy and the Marine Corps would provide the Marine Corps with another source of direction and guidance for its research and development program." It would assist the Marine Corps to identify desirable weapons, transportation, logistics, and other systems which could be developed in the immediate and near future and those which require additional basic research and/or exploratory development efforts. In short, such a forecast could provide a state-of-the-art timetable for the realization of the Marine Corps' Long Range Plan and Mid-Range Objectives.

"The state-of-the-art timetable should provide a basis which would assist the Marine Corps to develop new concepts involving tactics and techniques, and the organizational changes needed to implement them, to conduct future amphibious operations or to improve and refine current landing force concepts.

"Specifically, the forecast should permit the Marine Corps to identify more clearly and then pursue, in a meaningful manner, those programs which will either replace current weapons and equipment, or fill in the gaps which now obtain, in transport and combat aircraft assault and support amphibians, marginal terrain vehicles, command and control, air defense, target acquisitions, navigation and position location, power sources, logistics and materials handling.

"The forecast would enable the Marine Corps to procure more meaningful requirements statements (EDR, ADO, GOR, and SOR).

"In evaluating contractor proposals for exploratory and advanced development work, responsible agencies and their evaluation teams could use the forecast as a source of valuable information and guidance."

c. SOURCE: NAVMAT (MAT 311) CDR H. W. Merritt, Head, Requirements and Analysis Branch

Exploratory Development Goals (EDGs) are prepared to quantitatively express levels of performance for operational activities for the period 15 to 20 years hence. As goals, the EDGs are intended to influence technical development such that sound trade-off decisions can be made and a sound base can be provided for the development of hardware and weapons systems necessary to meet user objectives of this time period.

"In preparing EDGs, technological forecasts will be utilized in the following ways:

"1. In performing a parametric analysis of the various operational situations, levels of performance are established for one set of parameters from which values for the parameters under question are derived. Projections of technology are required to establish the initial set of performance levels. Such forecasts are also necessary to adjudge the attainability of the derived performance levels. By using technological forecasts in this manner, it can be determined that the goals are either technically achievable, or that the users' operational capability objectives require a technological breakthrough.

"2. The postulation of a plausible threat as guidance for research and development is an OPNAV responsibility. Such a postulation requires a projection of expected technical advances, an assessment of emphasis in any given technical area, and a judgment of relative progress in technologies between ourselves and an enemy. The thoroughness with which a threat projection is prepared by CNO determines the extent to which the Requirements Analysis Branch (MAT 311), Naval Material Command, must compensate by incorporating technological forecasts in a postulated threat.

"3. During preparation of the EDGs, trade-offs between operational capabilities can be identified. The practicality of making such a trade-off, the relative technical difficulty and the relative burden to be put on the factors being traded are all considerations requiring the use of a technological forecast."

d. SOURCE: NAVSHIP (formerly BUSHIPS) Mr. A. Schmidt, Program Manager, Advanced Ship Concepts

"The Advanced Ship Development Program must consider all logical competitive candidates when determining the most cost effective system to perform a specific mission. Since many studies may be underway at any one time, involving analyses of ship systems, systems of ships and on-ship systems, computerization of the elemental data is essential. By providing reliable values for technological parameters and capabilities and environmental factors the proposed forecast would be invaluable in providing reliable values for technological parameters and capabilities and for the associated environmental factors."

e. SOURCE: NAVORD (formerly part of BUWEPS) Mr. S. Marcus, Executive Director, Research and Technology

"BUWEPS has a dire need for technological forecasting. There can be no question of the utility of a forecast that can provide valid predictions that are of a high confidence level. A prime example of this need is reflected in the current exercise conducted by the Aircraft Office in developing future aircraft concepts. In order to develop these concepts, in essence they had to develop the technological capabilities that may be available in sub-system's areas. A credible Naval Technological Forecast could have formed the basis for this investigation so that the primary effort would not have been diluted (and perhaps duplicated).

"There are not many guides available for the planning of exploratory development programs. Presently existing are the GORs, which provide a guide by inference, the Goals for Exploratory Development which provide a more explicit end point. There is no doubt that an additional tool such as a Technological Forecast can provide the technical guide to develop a balanced exploratory development program."

Section 4. ARMY LONG RANGE TECHNOLOGICAL FORECAST

The Army Long Range Technological Forecast (LRTF) is prepared under staff supervision of the Chief of Research and Development and is intended to describe knowledge, capabilities and examples of materiel which science and technology can be expected to produce if supported by orderly programs of research and development. The document is used by operational and organizational planners, the combat developments system, and long range research and development planners in the Department of the Army in formulating new concepts, requirements, and plans.

The Army Long Range Technological Forecast is currently published in three volumes, as follows:

a. Volume One, "Scientific Opportunities," discusses the opportunities and limitations in both nonmateriel- and materiel-oriented research which will affect future technical capabilities of the Army. Where research effort to increase knowledge in specific areas is needed but not now in prospect, the area and the requirements are described.

b. Volume Two, "Technological Capabilities," describes the technical capabilities which are foreseen as achievable in areas vital to the provision of future high-performance materiel.

c. Volume Three, "Advanced System Concepts," includes examples of materiel systems which might be provided if the capabilities described in Volume Two are achieved.

LRTF is published by the Chief of Research and Development (CRD), Department of the Army. The Commanding General, U.S. Army Materiel Command, formally compiles and consolidates Army-wide critiques and contributions to this forecast with the close cooperation of the Army Research Office on behalf of CRD. The relationship of the Army Long Range Technological Forecast to Army planning documents is shown in Fig. 2.1. The forecast is one input to the "Basic Army Strategic Estimate." It is used by the Combat Development Command for the preparation of the Combat Development Objectives Guide (CDOG).

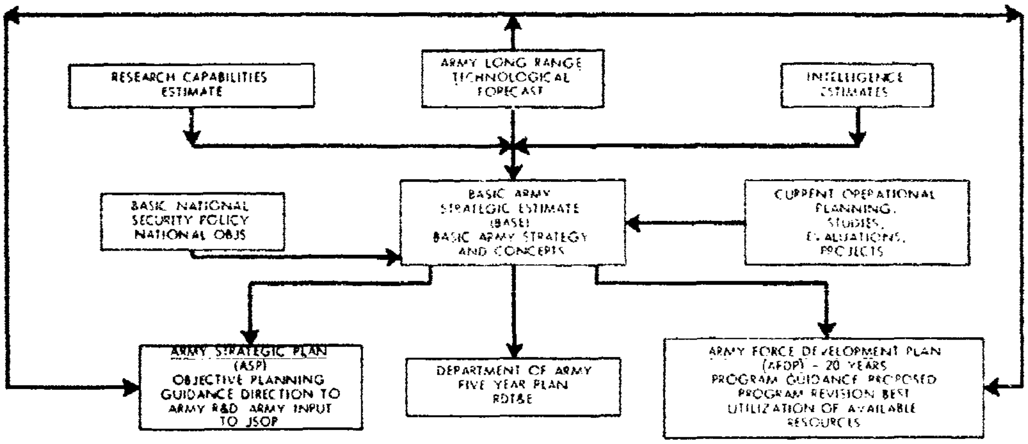


Figure 2.1. Role of Forecast in Army Planning Documents

In addition to the LRTF just discussed, the Army also conducts a series of Forecasts-in-Depth (FID). This series is designed to supplement the Army Long Range Technological Forecast. The Forecast-in-Depth is intended to provide an insight into specific technological fields for use by persons in and outside of the Department of the Army who have need for such background information. A Forecast-in-Depth is primarily an encyclopedic summary of the current knowledge, a projection of the expected technological environment during the next 20 years, and an analysis of the research effort required to attain the most promising materiel aspects. Its purpose is to allow the scientifically, technically, and operationally oriented individuals to communicate relevant ideas and learn of potentialities in a given field.

Forecasts-in-Depth, while generally comprehensive, are not exhaustive. Hence, the treatment may be properly considered an overall introduction to the current state-of-the-art and an extrapolation to forecast the technological environment of 10-20 years in the future. An extensive bibliography is included in each FID to document the current knowledge and to provide references for further detailed study.

Section 5. TECHNOLOGICAL FORECASTING IN THE AIR FORCE

The Air Force does not have a formal published forecast such as the Army's. They conducted two major technological forecasts in depth — The Woods Hole Study in 1958 and Project Forecast in 1963 — in which they related the predicted technological state-of-the-art to new system concept studies.

Figure 2.2 shows the organization of Project Forecast, which included analyses of threat, military capabilities, cost, etc. The forecasting of technology was done in the technical panels and was published in the individual panel reports. Continuity and updating of Project Forecast is accomplished by periodic review by the technical panels of the study.

The technological forecast finds utility in the following documents which are updated every 12 or 18 months:

a. Office of Aerospace Research Five-Year Plan. The Office of Aerospace Research (OAR) is responsible for the Air Force research program. Since OAR tasks are generally of a long-term nature, its goals must be forecast against relatively uncertain visions of the future. Nevertheless, in the interest of maximum economy and effectiveness in the use of our national resources, the OAR intends to proceed along carefully plotted courses of action. This year's

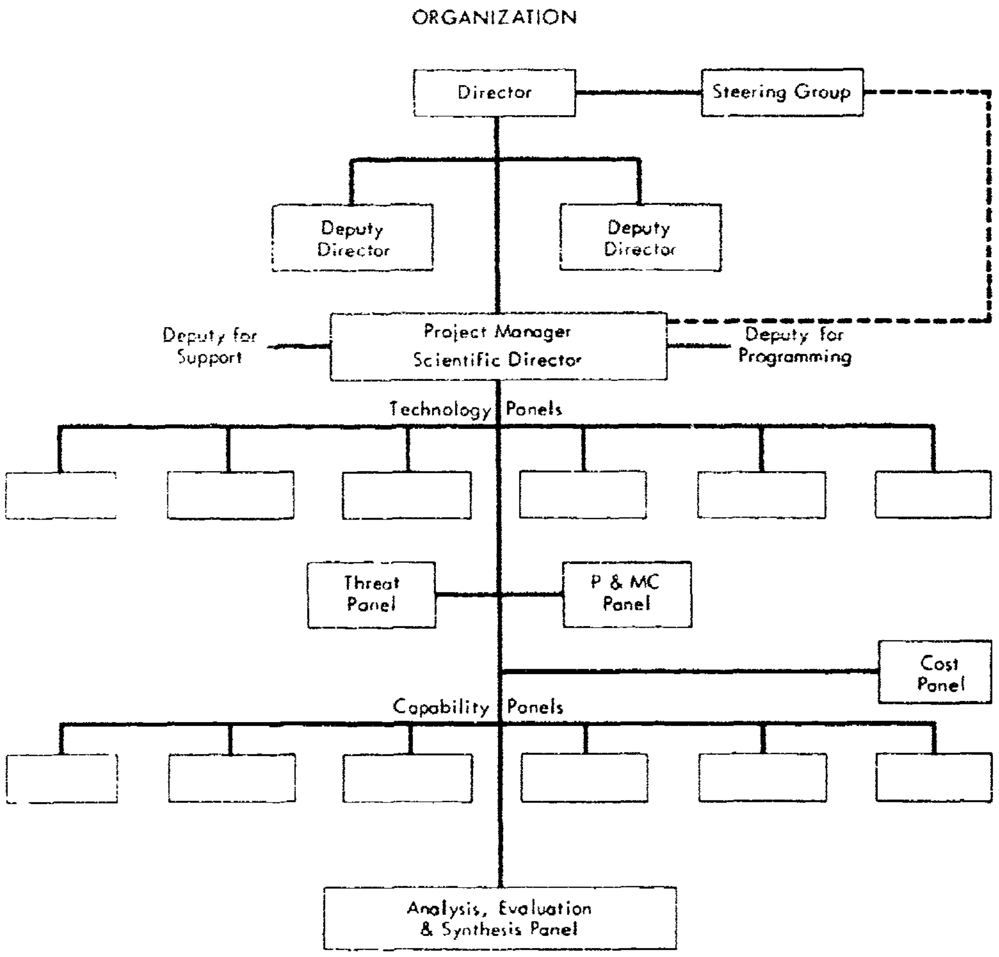


Figure 2.2. Organization of Project Forecast

Five Year Plan sets forth organizational and research objectives for FY 1968 through FY 1970, describes courses of action for their accomplishment, and presents studied estimates of the requisite resources.

b. AFSC Technological War Plan. The Air Force System Command's Plan for the conduct of R&D activity in support of its assigned responsibility consists of a basic plan and five supporting annexes. Purpose of each is briefly stated as follows:

The Basic Plan integrates the content of the annexes and provides the transition of planning effort into programs and budgets.

Annex A, Environment discussed the broad setting within which the technological threat and our military policy goals are evolved.

Annex B, Threat describes the expected evolution of aggressor systems and technology.

Annex C, Systems projects and describes concepts and capabilities which may evolve into the systems of the future AF force structure.

Annex D, Technology describes technology for deriving system capabilities and projects efforts to strengthen the Command's technological base.

Annex E, Resources projects mission man-years, technical facilities, and RDT&E funds necessary to develop tests and evaluate both technology and systems.

c. RDT Technological War Plan/Long Range Plan. This plan is prepared by the Research and Technology Division, AFSC, and describes the future course of action that the Research and Technology Division will take in managing the Air Force Exploratory and Advanced Development Programs. It is prepared by the scientists and engineers in the Air Force Laboratories. It is an attainable plan; it describes how RTD will allocate those resources which it may realistically expect to have available over the next decade. The plan is oriented toward achieving the level of technology required to attain the future Air Force capabilities identified by Project Forecast. It also recognizes that a major objective of this division is the building and maintaining in the laboratories of a strong in-house technical capability. Changes will undoubtedly alter various parts of this plan. Breakthroughs will occur and unsuccessful efforts will be terminated. On the whole, however, the plan represents a coordinated picture of where the RTD is going over the next decade, as seen now.

d. Technical Objectives Documents. These are prepared by the Research and Technology Division, AFSC, to provide means of communicating with science and industry, to describe the Air Force's objectives in each of 36 different technical areas. As is the case in any selective grouping of science and technology, it is difficult to draw sharp boundaries between areas and thus overlaps occur within the documents.

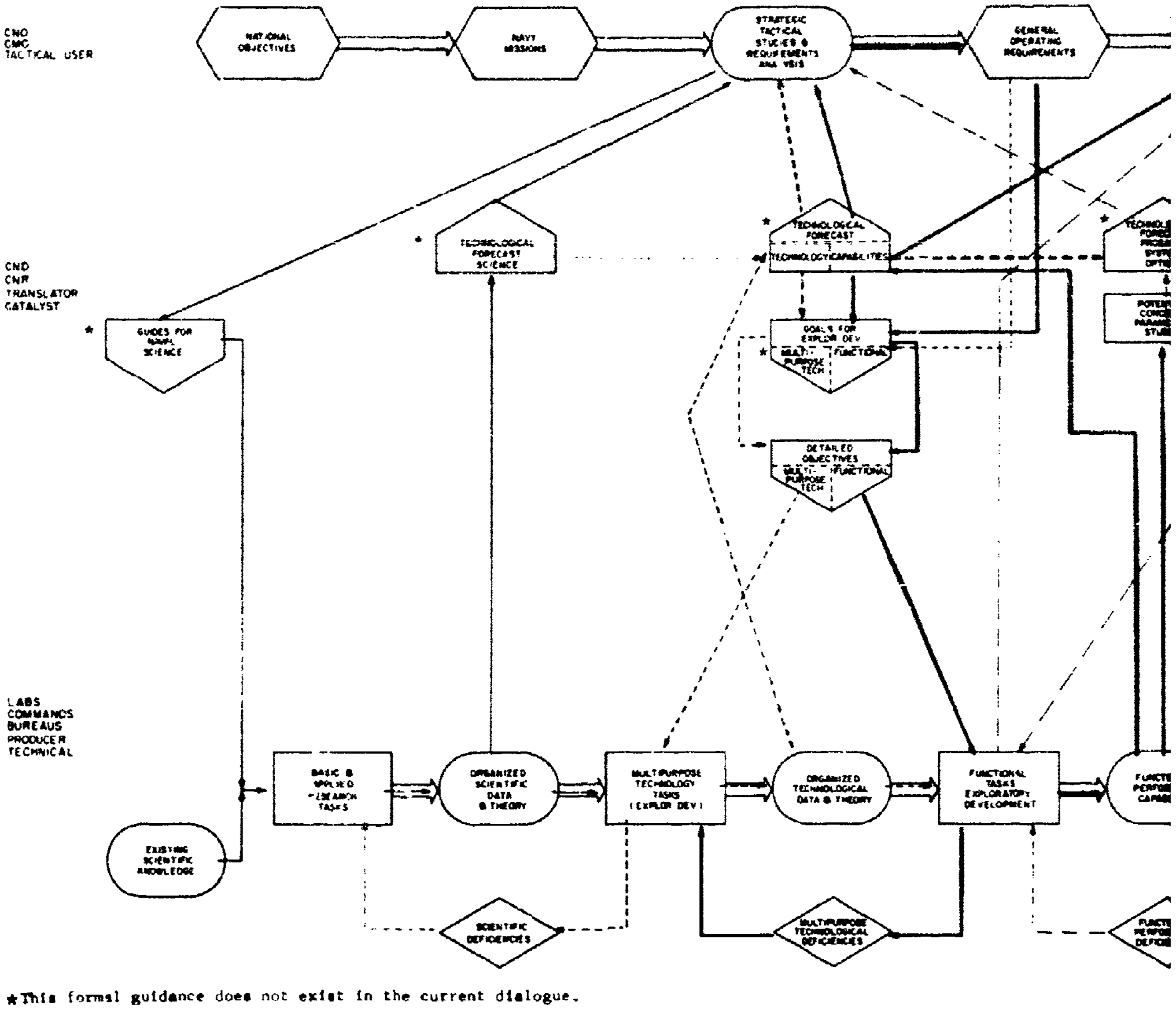
e. Technology for Tomorrow. The fifth and latest edition of which was published by the Aeronautical Systems Division, AFSC, in 1962, and which may be reinstated by the Research and Technology Division, AFSC, was a presentation of motivational concepts outlining the approach to an optimum plan. It was a guide to the organization and selective application of resources and capabilities for an aggressive support of the long range Air Force technical mission. The contents and organization of the document reflected the fact that a cohesive detailed plan exists collectively in the minds of the engineers, scientists, and management personnel who have contributed to its formulation.

Section 6. TECHNOLOGICAL FORECASTING IN THE MARINE CORPS

The Marine Corps presently employs the Army Long Range Technological Forecast, interpreting it in terms of specific Marine Corps applications. In addition, under Marine Corps sponsorship, the Syracuse University Research Corporation engaged in a study (Project 1985) in 1963-1964, entitled "The United States and the World in the 1985 Era," which examined "projected national objectives and policies, the international and domestic military, economic, and technological factors affecting the United States in the 1985 era." It is planned to update this document periodically unless the Navy produces a better document which will meet the requirements of the Corps.

Section 7. TECHNOLOGICAL FORECASTING IN R&D PLANNING

There is need for improvement in communications between the operating and technical communities within the Navy. The NTF is designed to provide a vehicle that can partially fulfill this need. Figure 2.3 illustrates the framework whereby the tactical-technical dialogue takes place. There is shown an upward flow of technical capabilities, forecasts, and systems concepts which meets with the objective of mating with the constraining downward flow of missions, technological goals, and operational requirements. The scientific community "proposes" technological capabilities while the operational community "disposes" to fulfill strategic and tactical needs.



*This formal guidance does not exist in the current dialogue.

Figure 2.3. Tactical - Technical - Dialogue and Flow

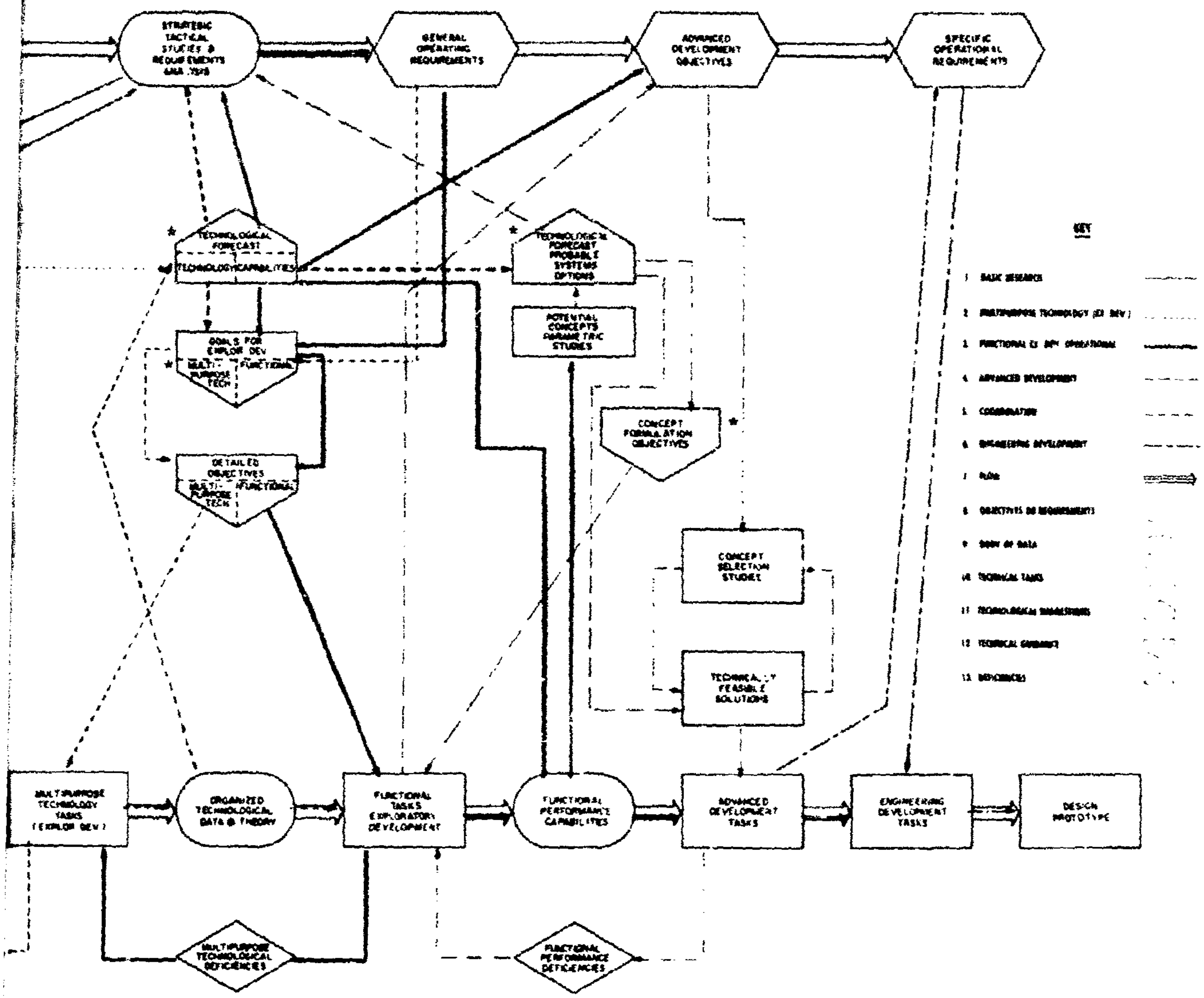


Figure 2.3. Tactical - Technical - Dialogue and Flow

A technological forecast of scientific and technical capabilities can constitute a vital part of the overall tactical-technical-dialogue. The forecast can assist in establishing guides for Naval Science and Exploratory Development Goals by making available capabilities leading to concepts and suggestions for developing requirements. What may be seen from this chart is that the goals translate tactical requirements into technical objectives and the forecast translates technical capabilities into strategic possibilities.

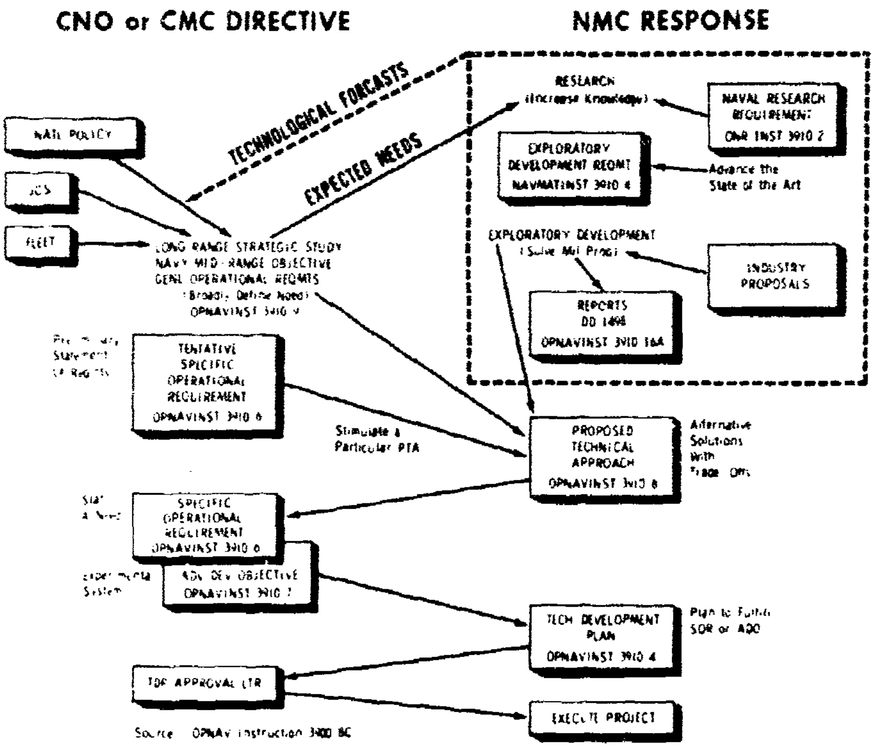
The forecast and the goals form a two-way street. Ideas and desired capabilities which are gained in developing the goals might show up as missing in the forecast. Conversely potentials which would otherwise not be considered in the plan will turn up in the forecast. If the forecast is good, it can be a repository of avenues of technical approach from which choices can be made in developing the goals.

Figure 2.4 illustrates the functional status of the technological forecast within the flow sequence of planning documents. It is shown that requirements are assessed against feasibilities as referenced to time, with two important planning criteria outputs:

a. Technological constraints or limits imposed which serve to define feasible performance in relation to desired performance.

b. Implications for the reorientation or shifts in emphasis in defined areas of research and development.

This process further illustrates the requirement for and gains to be derived from the technical-tactical dialogue process.



Source OPNAV instruction 3900 8C

Figure 2.4. Technological Forecasting's Position in the Documentation of Requirements for Developing Effort

It can be seen from the Technological Forecasting Group's proposed R&D planning sequence in Fig. 2.5 that technology, including technological forecasting, as well as threat and policy determinations, play a major role in developing operational objectives. An analysis of these operational objectives and current and projected technology result in exploratory development goals and/or technical objectives. The goals/objectives are then appraised technically and alternate approaches are considered prior to being incorporated into the technical plan. This technical plan when approved should serve as a basis for the procurement of resources, as well as the generation of the technical program. This procurement and program generation should go on concurrently so that the time frame may be sharply reduced. The technical program is then broken down into R&D tasks and performed either by government or contractor groups. The crucial point in this whole R&D planning system is the feedback concept in which the technical information generated in the R&D tasks is fed back into threat and policy where it may affect the operational objectives. In other words, the whole planning sequence is an iterative one and dynamic technological forecasting is not only an ingredient but indeed a catalyst.

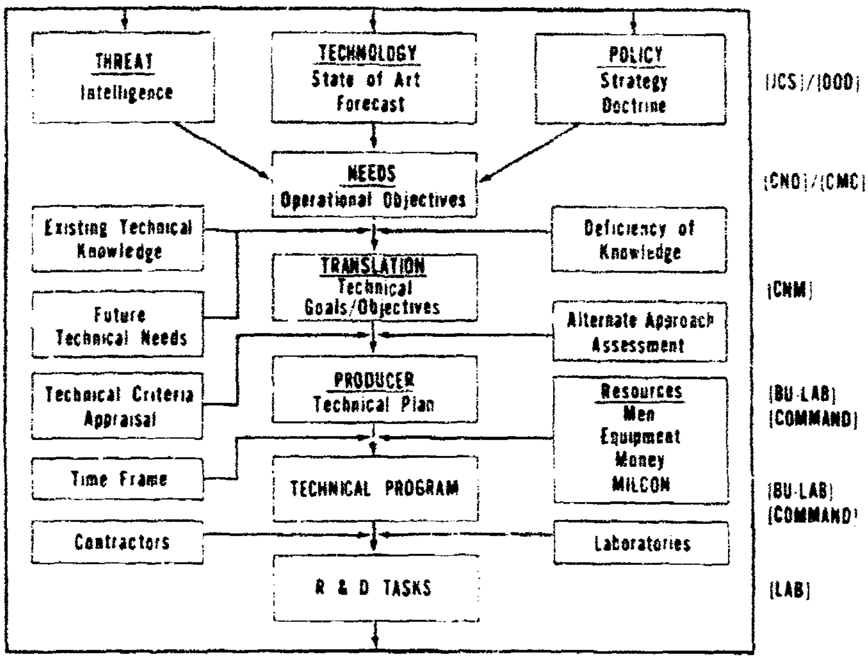
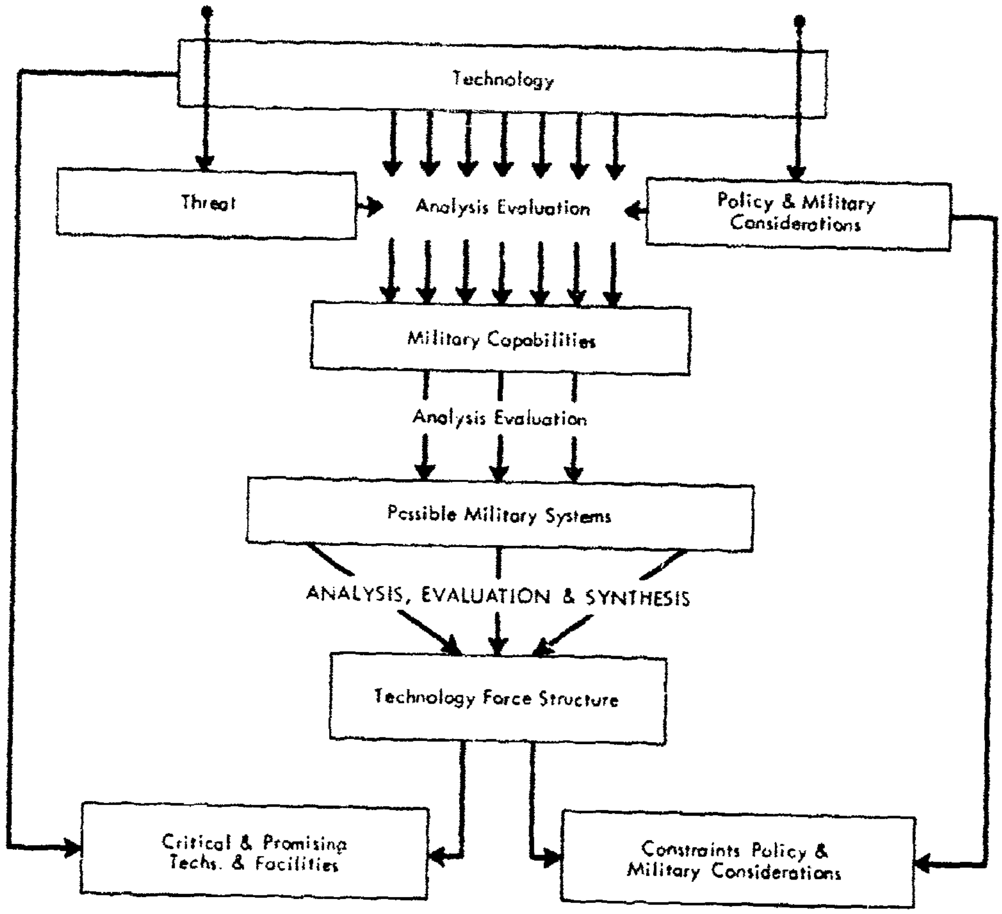


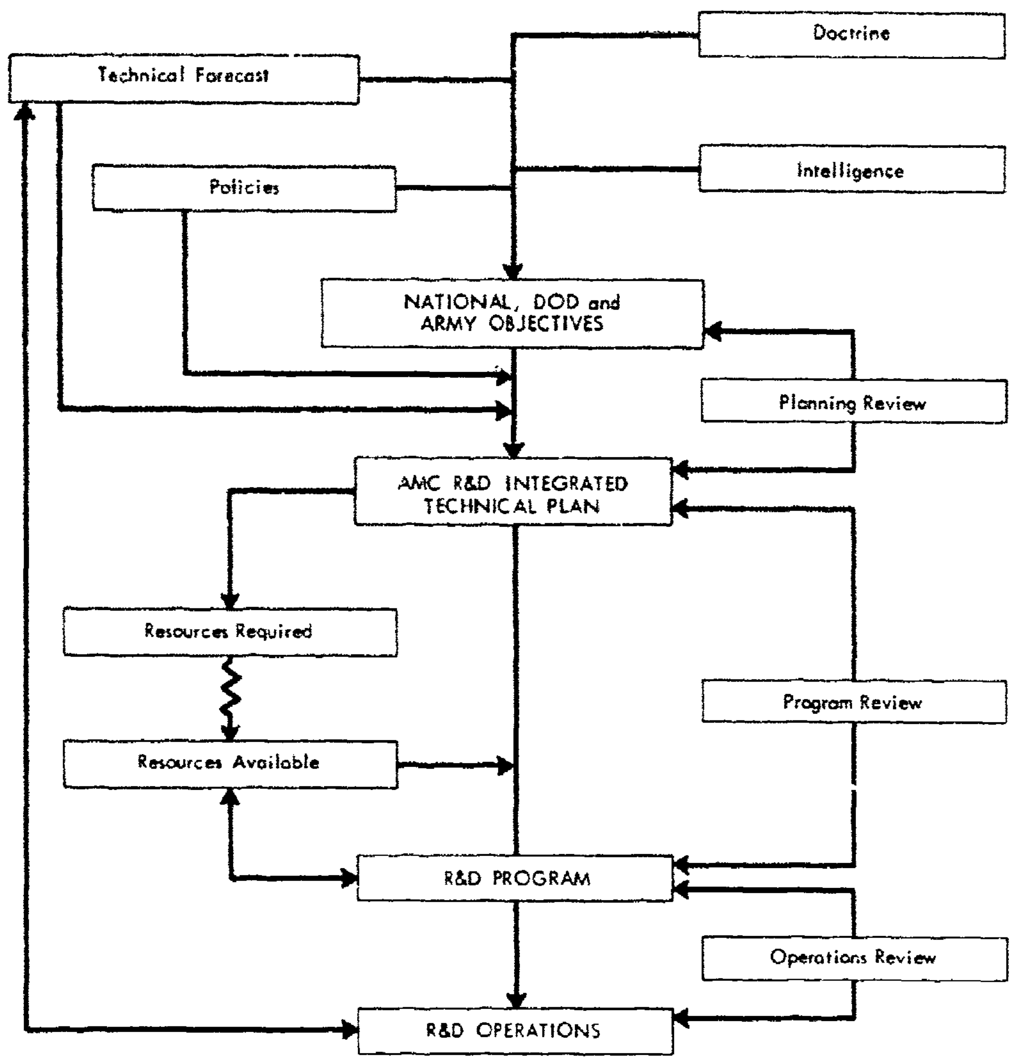
Figure 2.5. An R&D Planning System for the Navy as Proposed by the Group

Figure 2.6 and Fig. 2.7, respectively, illustrate the functional status of the technological forecast in the Air Force and Army long range planning framework. The forecast functions and utilization are seen to be analogous for all three services.



Source: Air Force Project Instruction Manual of 1963

Figure 2.?. Project Forecast Flow - Air Force



SOURCE: AMC Pampnlet - AMCP 705-1, Volume 1, of January 1966

Figure 2.7. R&D Planning Interrelationships - Army

CHAPTER 3

FORECASTING METHODOLOGY

Section 1. INTRODUCTION

This chapter will discuss, in turn, the control of uncertainty in the application of science and engineering to planning functions, the science of technological forecasting, forecasting techniques, and techniques for expressing technical trends. The information herein will assist the forecaster in understanding what a forecast is, what factors make for a useful forecast, and the constraints imposed by nature and other forces on the extent to which technological trends may be forecast.

Section 2. MANAGEMENT OF UNCERTAINTY

THE MEANING OF A FORECAST

Modern management emphasizes consideration of future events at times of decision. In small organizations, the facts, projections, and probabilities may be the responsibility assumed by a single individual. In larger organizations and in a time of changing technology, the structure, facts, and probabilities are processed by more sophisticated information systems.

To accomplish long-range research and development planning, two fundamentals are prerequisite. First, one must have clearly in mind the future objectives to be achieved. Second, one must have a relatively clear knowledge of the anticipated state-of-the-art in the several supporting sciences and technologies at the time when they will be exploited to achieve these objectives.

A technological forecast is a realistic estimate, by technically knowledgeable persons, of the rate, direction, and extent to which a particular technology or group of technologies will develop in a specific period of time. Its purpose is to separate clearly the more likely technical states from the less likely.

A forecast is not a plan, it is not to be construed as a commitment that material or a technical achievement will be available at the time or in the form indicated, or that it will be developed at all. It will not predict breakthroughs nor will it describe the innovation.

Technical forecasting does, however, indicate that a significant advance is in the offing and suggests probable timing of the advance. Thus, by providing a continuing state-of-the-art assessment, a primary value of technical forecasting is the early recognition of a scientific development which in turn allows for timely response.

Technological forecasting alone cannot determine what will have been accomplished in science or technology by some future date. The technological future will be determined by a number of factors, including financial support, the number of scientists or engineers working in a particular field, the number of new ideas or innovations introduced into the field, and a communication or interplay factor among the men and ideas.

NOTE: The discussion presented herein is based largely on material previously published in official and unofficial U.S. Army publications which has been adapted for the special purposes of this report. The reader may consult Appendix E, references (1) through (5), for a more complete coverage of forecasting methodology, and the major individual contributors.

A technological forecast itself must communicate. It must stimulate operational minds, but within the bounds of technological feasibility. It must satisfy technical minds that it is reliable and relevant within professional standards. To reach both these minds, it must be presented concisely, quantitatively, and accurately.

The development and analysis of technological forecasts can be an effective influence in the creative thought processes which are essential to dynamic management. Each projection requires careful consideration of the factors which influence the indicated progress. As apparent inconsistencies and barriers become evident, attention and effort must be focused on their removal. The necessity for innovation is projected well in advance so that the usual procrastination in introducing change may be overcome.

In the long run, it is not enough that a technological forecast serve only general communication. It must find its way into the formulation of plans, programs, advanced designs, allocation policies, and other management functions. Continuous revision and feedback from users will be required to create a recognized valuable management tool. Since decisions usually tend to be made in the general direction of existing progress trends, one of the most important functions of the accurate technological forecast is to insure that such decisions do not result in "too little—too late" or in "too much—too soon."

VARIATION AMONG TECHNICAL FIELDS

Naval technology embraces a wide spectrum: ordnance, logistics, protection, communications, medicine, toxics, detection, environment, human factors, surveillance, to mention a few major areas. The basic and applied sciences feeding into these military technologies are even broader, perhaps as broad as almost all science and engineering. Furthermore, the science and research sponsored under one technology usually produces inputs to other technologies. Research in power sources, for example, could change the configuration of ordnance systems as well as transportation systems. Research in immunology could change medical practice or biological warfare vulnerability. Research in lasers could change communications systems and/or antipersonnel weapons. Micrometeorology research for chemical warfare also applies to surveillance, and so on.

There is a natural tendency for research and engineering sponsored under any one technology to be forecast in terms of applications to that technology. There is also a tendency for forecasts to include only the currently justified and sponsored research and engineering. While these tendencies are natural and always expected, they are prejudicial to the breadth of vision a forecast should possess ideally.

The initial attitude toward forecasting is quite different among the various scientific and engineering fields. It would be a dangerous oversimplification to characterize these attitudes by field in sharply-defined terms. But for the sake of illustration, and for sympathy with the forecasting specialist's problem, the following examples are given. The physicist is said to favor the random-breakthrough concept of future technology, which implies that one does not forecast, one waits until it happens and then sees how it affects applications. The engineer or applied scientist is sometimes accused of being reluctant to forecast because he tips his hand and gives development or patent possibilities to his competitors. The biomedical scientist is reluctant to forecast, it is alleged, because critical experiments, not parameter extrapolation, is the procedure for progress. The systems designer is leery of forecasts because component and subsystem progress depends on resource-allocation decisions made by people over whom he has no control.

One objective of formal forecasting is to develop a realistic and acceptable, common philosophy toward forecasting among technical fields.

Section 3. SCIENCE OF TECHNOLOGICAL FORECASTING

EARLY MODELS

Technological forecasting has no established epistemology, no recognized theory or science of methods. At one extreme we find an apparent willingness to assign this function to the very imaginative science fiction writers; at the other, a suggested requirement for a very scholarly approach. Alexander[1] presents a very reasonable case for the "Jules Verne" school and gives evidence of the success of this approach. Gilfillan, in considering the prediction of invention,[2] merely specifies some 38 principles of invention. These principles might, through the inductive method described by Bacon and illustrated in Darwin, yield a skeleton about which a forecast methodology could be built. In any event, the methodologies suggested by Alexander or induced from Gilfillan could be classed simply as "forecast by informed judgment."

Lovewell and Bruce of the Stanford Research Institute[3] suggest that the forecast can be accomplished by "thorough logical surveys of current and conjectured applications of science—and of their consequences," and describe such an approach in reasonable detail. Their primary departure from Alexander, more so than from Gilfillan, is to augment the simpler "informed judgment" approach by introducing a requirement for an explicit statement of the rationale leading to each prediction.

Lenz[4] departs from the essentially single point predictions of the previously mentioned and addresses a procedure for forecasting by "trend extrapolation." Here we find an indication that a model for technological forecasting might be built; that analytical techniques might be applied to assessing the technological future; that a tool can be derived to provide a means for assuring dispassionate application of the informed judgment of scientific and technical expertise.

The case is made for the relative roles for analysis and for judgment by Secretary McNamara when in speaking about system analysis, or, as he called it, "quantitative common sense," he said. "I would not, if I could, attempt to substitute analytical techniques for judgment based on experience. The very development and use of those techniques have placed an even greater premium on that experience and judgment, as issues have been clarified and basic problems exposed to dispassionate examination. The better the factual basis for reflective judgment, the better the judgment is likely to be. The need to provide the factual basis is the reason for emphasizing the analytical approach."[5] In precisely this sense can the general character of the desired technological forecast model be described: a tool to insure that factual bases are used for reflective "informal judgment."

SERIOUS SCIENCE FORECASTING AND SCIENCE FICTION

The art and science of technological forecasting is young. It almost seems contradictory to the rigorous standards of evidence taught in professional education. It may seem closer to science fiction than to fact. For this reason, reputable professionals are often hostile to or skeptical of technological forecasts. Yet for the preparation of the navy technological forecast, the best qualified persons are desired. The very mind which has been steeped in the facts and figures of a field for years and which creates hypotheses, experiments, or designs "at the bench," is the one which can make professional conjectures with realism and restraint.

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[1] The Wild Birds Find a Corporate Roost, T. Alexander, Fortune Magazine, Vol. LXX, pp. 130ff (Aug. 1964).

[2] The Sociology of Invention, S. C. Gilfillan, Follet Publishing Co., pp. 5-13 (1935).

[3] How We Predict Technological Change, P. J. Lovewell and R. D. Bruce, "New Scientist," Vol. 13, pp. 370-373 (1962).

[4] Technological Forecasting, R. C. Lenz, Jr., Rpt Nr ASD-TDR-62-414, June 1962, Wright-Patterson AFB, Ohio, pp. 19-73 (DDC No. AD 408 085).

[5] "McNamara Defines His Job," New York Times Magazine, April 26, 1964, pp. 107ff.

The technical expert is not asked to create science fiction. The laws of nature as known in his field are both the vehicles and the boundaries of serious projections. He is not asked to recite these laws or to write a text on what is known in his field. He is asked to sit back and think a little differently, synthetically instead of analytically. In order to plan his next experiment or design in everyday work, he sorts out critical issues which stand in the way of mental acceptance of a smooth-flowing set of propositions. This or that proposition or issue needs test or demonstration. In forecasting, he is encouraged to examine the same universe with the same rigor, but to visualize the implications of the confluence of laws, possible results of new experiments and trends within limiting factors. This is not science fiction. It is just another mode of responsible professional thinking which heretofore was unverbalized and uncommunicated but which now, in the age of technological strategy and tactics, must be articulated and integrated with other information to maximize organizational survival and growth.

THE "BREAKTHROUGH" ARGUMENT

There arises an argument: You cannot predict breakthroughs; therefore, why predict at all?

Breakthroughs rarely occur. Examples like incandescent filaments, penicillin, transistors, and lasers are often used. But if history is examined a little more closely, one will discover long intervals between a hypothesis based on fairly solid previous knowledge and a demonstration of fact or feasibility.

Breakthroughs are partial. They seldom are sufficient to change systems and applications overnight. They may affect components and methods, but these are tied in with larger systems which are rooted in the past and present by an environment of many other components and methods. Systems evolve into being; they do not suddenly jump into being.

Breakthroughs can be the expected products of only a very small fraction of the R&D effort. The majority of research and development progress is accomplished by small steps, tedious competent work, many frustrations, and incremental gains.

Breakthroughs may not be predictable in time of occurrence, but their effects can be estimated if they occur at predicted times.

This last point supports arguments for a fertile and well-integrated technological forecast as a document and source of information. Unless the future image is knit closely together, with the interactions between purposes, systems, and technology spelled out, the estimation of the impact of hypothetical or anticipated (in the sense of betting) breakthroughs is a wild and uncertain exercise. With all the information tied together, and the technological forecast a vital segment of the information, the impact of breakthroughs can be examined logically.

THE "STATUS QUO PRESERVATION" ARGUMENT

The argument is made that the future tends to fulfill an image, not because of any magic, but because the image is a focus for shaping events. Consciously or subconsciously, the image is used by persons to organize otherwise chaotic bits and pieces of experience and information. Raw data are converted into information when the sensory input is screened for its relevance to the image. Reconfiguration of the image is partly conditioned by the historical flow of sensory information. The course of history may well be interpreted as causally related to the succession of images of the future held by persons along the way.

Forecasters and users of forecasts must be aware of the possible implications of this argument because the technological forecast is a collection of images of the future, no matter how it is separated or consolidated. One of these implications is "preservation of the status quo." If a forecast is just a rehash of a long-range R&D plan (the latter having been prepared first and justified with a supporting program), then the forecast is being used to validate the plan. More properly, a plan is a consequence of the forecast and other factors, and the plan should change annually with the new round of forecast information, requirements information, and budget levels.

The forecast could be misused by management in such a punitive manner that the forecast is forced into the straitjacket of a commitment. If forecasters are held responsible for the truth of their forecasts, they will tend to be conservative in predicting progress and change and will underestimate the rate of change to keep it under control.

SOPHISTICATED PREDICTION MODELS

With the state-of-the-art in technological forecasting as underdeveloped as it is, the Navy Technological Forecast (NTF) is not an attempt at sophistication nor is it a requirement that the forecasters develop sophisticated tools and techniques for forecasting. Years of "research on research" and "planning of planning" must precede a technology of technological forecasting. What is desired now is substantive information with as much breadth and reliability as possible, without knowing how to measure either.

BALANCE: CONSERVATISM VS. OPTIMISM

In the long run, the utility of a technological forecast will depend upon the good professional judgment of the forecasters. The judgment referred to is the technical judgment, not value judgment. A scientist or engineer may believe that a technology is feasible or likely, but disagree with the social/economic implications. When addressing the technical question, only the technical answer is desired.

The easiest way to undermine or unbalance a technological forecast is to address it only to technical questions which have obvious immediate payoffs. Safeguards must be erected against this possible shortcoming of a forecast.

Another serious problem of balance exists in the possibilities of overstatement and understatement. A very conservative forecast may imply low risk for the forecaster and high risk for the planner. A very optimistic forecast may have high risk to the forecaster and low risk for the planner. However, these risk statements may be reversed when the natures of the risks are examined.

CONDITIONS AND CONTINGENCIES

Trends convey the semantics of growth, development, evolution, progress, direction. The planner needs, in addition, a sense of the boundaries and restrictions, a sense of proportion and likelihood. All too often, a technological forecaster may show vistas and scenery without the road map and the hazards along the way. Whereas good salesmanship is supposed to favor the vista approach, sincere judgment is desired in the technological forecast. The sincerity of a forecast can be conveyed by an honest and communicative appraisal of the conditions, contingencies, rates, phase changes, limitations, and complexities which impinge upon the trend. Graphics are useful adjuncts to the written word in showing these limitations.

Sometimes applied research, and often basic research, is characterized as "inner motivated," meaning that the path of progress depends on the results at each step. A forecaster may be reluctant to nominate the final path in prospect because he does not know the specific results at each step. On the other hand, he may know the general objective and the possible alternatives at various junctures in the branching process.

The trend of technology in terms of naval applications may, in some fields, be conditioned by forces outside the control of the in-house R&D community. The trend may depend on the reaction of relatively disinterested parties. One example may be the synthesis of pharmaceuticals or the engineering of complex biomedical instrumentation. Industry R&D governed largely by consumer markets will be the main source of technological advances for many naval applications. The forecaster's problem is to describe the likely progress of industry in response to the consumer market and to anticipate the incidental advances for naval application.

Section 4. FORECASTING TECHNIQUES

FORECASTING BY EXTRAPOLATION

The most obvious method of technological forecasting is to assume that whatever has happened in the past will continue to happen in the future, provided there are no disturbances. This most common method is the extension of some form of time series on the basis that existing trends will continue. While it is not a very accurate method, most intuitive forecasts of progress are probably based on subconscious versions of this technique.

Two basic assumptions must be made to use this method:

1. That those forces which created the prior pattern of progress will more likely continue than change.

2. That the combined effect of these forces is more likely to extend the previous pattern of change than it is to produce a different pattern.

The method is applicable to forecasting the functional capabilities of man, i.e., the end result as opposed to the means of achieving some objective of man. For example, moving, communicating, illuminating, computing, etc., are functional capabilities defined as being independent of any specific technology—although in fact being based on all applicable ones. If the field of interest to the forecast centers on man's ability to communicate, appropriate data sets might be "frequency spectrum exploitable" or "number of intelligence bits per hour per mile of separation between communicators." Such a set of data does not explicitly concern itself with whether the desired function is to be accomplished by cable, microwave, teletype, or a Telstar satellite. One or more of these techniques must be implicitly involved. The growth is considered in terms of cumulative time or calendar year. Typically a plot of functional capability versus time displays the exponential character of growth (Fig. 3.1).

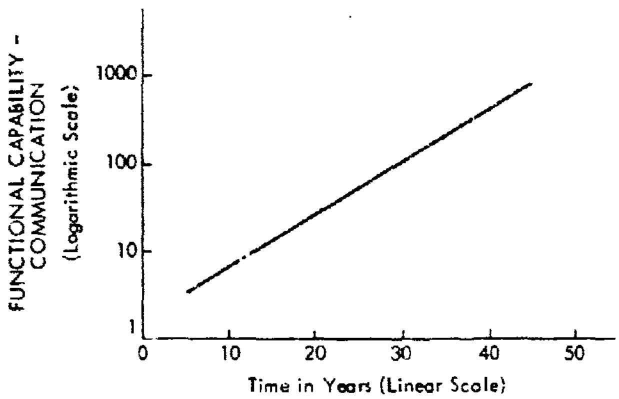

Figure 3.1. Typical Functional Capability of Time History (Semilog Plot)

The farther the forecast extends into the future, the greater the probability that one of these above assumptions will become invalid.

A more valid method of forecasting future trends of R&D activity, and related funding is to compare them to typical biological growth phenomena.

FORECASTING BY GROWTH ANALOGIES

Technological progress, as we are currently witnessing, more than likely proceeds in an exponential manner similar to the law of acceleration under the influence of gravitational forces or to the phenomena of biological growth. Initial advance is exponential, followed by a continued diminution of the rate of advance as "maturity" is approached. The synthesis of several fields of progress, each occurring at different intervals, may result in an exponential advance for a functional capability.

Consider trends of specific techniques which enable a functional capability to be accomplished. In the communications field, one set might consider the historical growth of a bandwidth capability of microwave links. This class of data, which might well be called "Specific Technique," follows a characteristic curve (Fig. 3.2). Initially the technique tends to experience a period of slow growth. It might well be hidden in a laboratory at this time or buried in a patent office. Finally, its potential is recognized, money and work are poured in, problems are resolved, and an accelerated growth occurs. Eventually, limiting factors are encountered, the growth rate decelerates, and the curve asymptotically approaches some upper value.

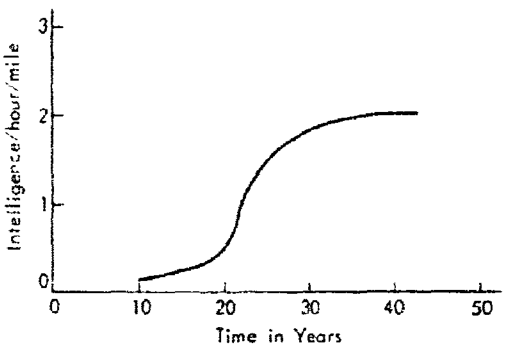

Figure 3.2. Trends in Techniques Leading to Functional Capability (Linear Scale)

FORECASTING BY TREND CORRELATION

The trend of a technical parameter which is complex and difficult to predict by itself may sometimes be more easily expressed as the result of a relationship between two or more other trends.

In order to use two or more trends to determine a third, the predictor must have available a number of primary trends which are related to the technical field of interest. To these he must add a knowledge of probable relationships that might arise from combinations of such variables. The predictor may then select the relationship and the primary variables which influence the desired technical improvement. The trends of the primary variables may be projected on the basis of any techniques which appear appropriate. The prediction is then completed by projection of the unknown variable on the basis of the relationship between the primary variables.

Time series may be used in quite a different way for prediction by taking account of characteristics in the trend curves of the time series.

One of the simplest situations for prediction on the basis of trend characteristics is one in which the extension of a well-established exponential rate of progress intercepts a known physical limit. Since, by definition, progress cannot extend beyond this limit, only two predictive possibilities exist. The first, obviously, is that progress will indeed stop at this point. The second is the development of new technology that will permit the extension of progress on some equivalent basis beyond previously known limits.

DYNAMIC FORECASTING

In a method of technological prediction based on the technique of "Industrial Dynamics," technological progress is based upon a mathematical expression of the influence of those factors over which control may be exercised. These factors include the numbers of people trained for a given research and development function, the number of people employed to perform that function, and the facilities provided for experiment. The effect of each of these factors and the feedback relationships are combined in equations which provide a prediction of the technological progress to be obtained from a given input of the factors involved. The greatest difficulty in this method of technological forecasting is the determination of the transfer coefficients which relate quantities of the input factors to the quantities in which technological progress is measured. In most cases the transfer coefficients will necessarily be based on the empirical relationship which has existed in the past between the input and output factors.

DELPHI TECHNIQUE

The Delphi technique is a unique method employed for the systematic solicitation of expert opinion. Instead of using the traditional approach toward achieving a consensus through open discussion, this technique "eliminates committee activity altogether, thus ... reducing the influence of certain psychological factors, such as specious persuasion, unwillingness to abandon publicly expressed opinions, and the bandwagon effect of majority opinion. This technique replaces direct debate by a carefully designed program of sequential individual interrogations (best conducted by questionnaires) interspersed with information and opinion feedback derived by computed consensus from the earlier parts of the program. Some of the questions directed to the respondents, may, for instance, inquire into the 'reasons' for previously expressed opinions, and a collection of such reasons may then be presented to each respondent in the group, together with an invitation to reconsider and possibly revise his earlier estimates. Both the inquiry into the reasons and subsequent feedback of the reasons adduced by others may serve to stimulate the experts into taking into due account considerations they might through inadvertence have neglected, and to give due weight to factors they were inclined to dismiss as unimportant on first thought."[6] RAND Corporation's long-range forecasting study used this technique.[7]

INTERPRETATION OF FORECAST DATA

Selection of a parameter to be considered in a forecast, as previously noted, involves the consideration of functional independence. One could, for example, plot the cost of light per lumen. Such a plot, however, would implicitly consider the efficiency of the energy conversion device, the cost of the energy consumed, and perhaps even the impact of governmental taxing policies or restraints on transportation of the energy source. Thus, cost of light per lumen, while a feasible parameter to establish, appears to be subject to too many constraints.

Instead the forecaster is better advised to concentrate on such parameters which he might be able to control. An excellent candidate for analysis, perhaps, is "efficiency of energy conversion." A somewhat easier variable to present is "lumens per watt." Such a curve is plotted in Fig. 3.3. Although it is not necessary to do so in a working plot, certain points are identified in Fig. 3.3 for purposes of the example. The data points address themselves to particular technologies which are the current basis for the functional capability described in the associated trend curve. The dotted line constituting the forecast portion of the plot is an extrapolation of the growth trend.

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[6] See "On the Epistemology of the Inexact Sciences," by O. Helmer and N. Rescher, Management Science 6 (1959), p. 47.

[7] T. J. Gordon and O. Helmer, RAND Corporation, "Report on a Long Range Forecasting Study," RAND Report P-2982, September 1964.

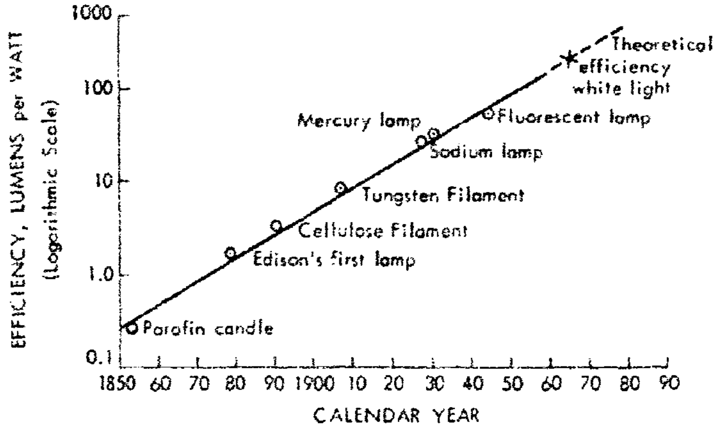

Figure 3.3. Functional Capability Trend of Illumination (Semilog Plot)

One may reasonably ask as to the validity of a continued exponential extrapolation. This question, for the present, can best be answered in only two ways. Experience demonstrates such an extrapolation to be appropriate. Second, reflection upon the growth factors at play seems to indicate that until some physical limit is reached, an increase in functional capabilities is to be expected. Intuitively one would expect that the exponential increase in the number of working scientists, the exponential increase in the number of technical periodicals and published papers, and the similar increase in the funded support of research experienced today would combine to result in such a growth pattern.

A detailed study of historical growth in terms of the demonstrated functional capability would not reveal the deliberate day-by-day enhancement suggested by the chart. In fact, a continuing series of perturbations, of step-like advances and plateaus, would be seen, and properly so. If the trend line is an indication of the potential upward limit of a functional capability at each point in time, the limit is realized only when a decision is made to exploit all of the available pertinent knowledge. Where nothing new and better is made, a plateau results.

The possibility always exists that the situation seen for the illumination example will occur; physical or natural limits are being approached with increasing frequency in our current technological society. For example, today one measures thicknesses in single wavelengths of light, electronic components in terms of molecular sizes, and so on. When this situation occurs, one can only terminate the curve at the limiting point and suitably annotate the chart. Such information is clearly useful in avoiding an undertaking that the scientist recognizes as a theoretical impossibility.

Figure 3.4 is a plot of the growth curve of the conventional incandescent bulb and the fluorescent lamp, both current techniques for converting electric power to illumination. Growth points are identified to indicate the manner in which the plot has been prepared. The shape of the curve shows a rather limited growth during the early experimental years of the technology, then an explosive growth toward increased efficiency and, finally, a tapering off as the growth curve appears to approach an asymptote. The relationship between this plot of technological advance and that of functional capability is apparent. Each specific technology contributes just a small portion to the overall functional capability growth. At best, each offers only a few data points to the long-term technological growth curve and assists in understanding or interpreting the capability curve. Thus, the functional capability forecast is biased by, but is independent of, any particular technology. One may ask the significance of the functional capability plot (Fig. 3.2) to the planner. Care must be exercised to insure that projected capabilities reflect actual potentialities of the specific techniques included in the presentation. For example, Fig. 3.5 presents capability curves for two functionally similar technologies, one old, one new,

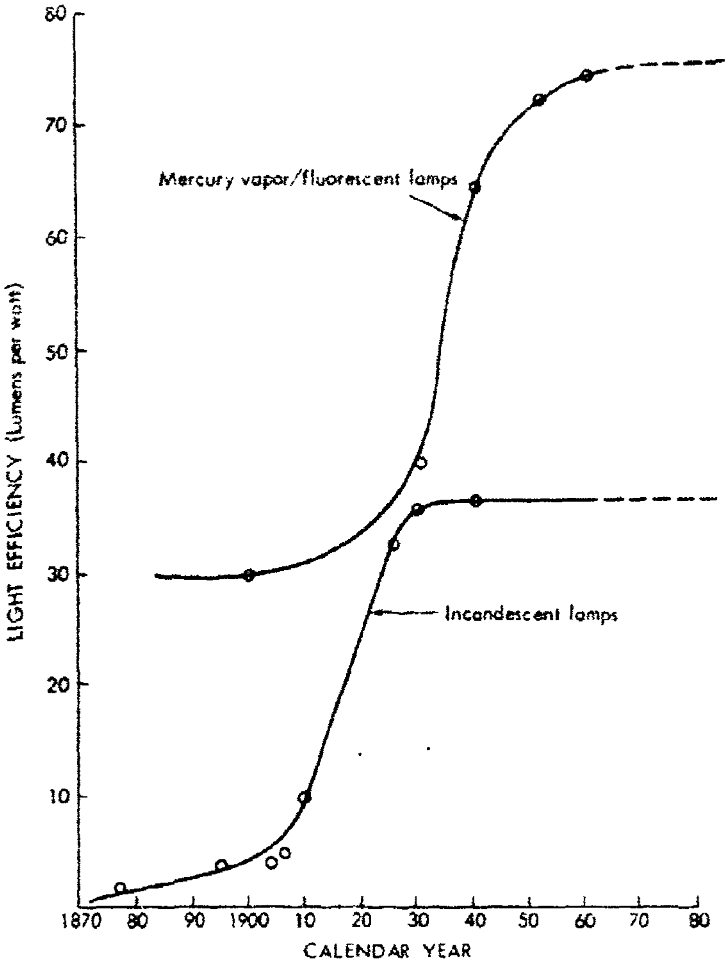

Figure 3.4. Specific Techniques--Illumination

and identifies a number of critical points. At time 32, one may or may not have reason to believe that the "old" technology is going to reach a growth limit. The "new" technology has shown little development. At time 30, a conservative technological capability forecast of the two would appear as Fig. 3.6.

At this time, the manufacturing arm of a given industry, for example, would have little cause for interest in the new technology. The research facility is well advised to monitor the new technology and, depending upon management policy, to explore it to some depth. To some extent the appropriate relative level of research expenditure can be adjusted as a function of the slope at any point between 0' and 1'.

As the new technology curve moves into the region between 1' and 2' (Fig. 3.5), a potential for exploitation is evidenced. Here the forecaster must ask questions as to the status of the old technology. If the older, and more common, technology continues to show an expansion potential such as is seen about time 38 in the growth curve, he might be well advised to continue the new technology at a research and development level, or at best, to prepare to exploit

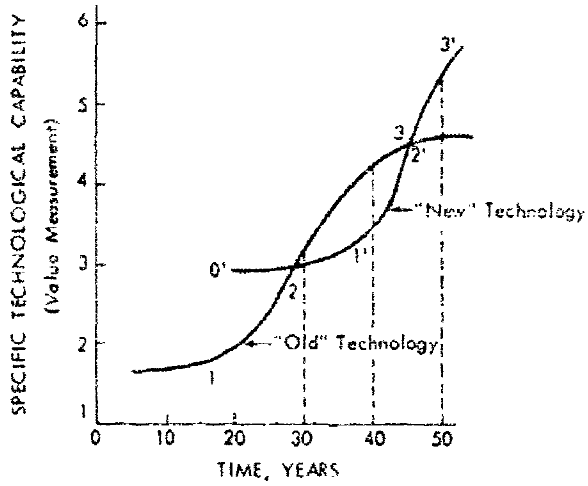

Figure 3.5. Historical Trends for Two Known Techniques

the new technology in his long-range planning. On the other hand, if the older technology is approaching the stagnation region evidenced beyond section 3 and the new technology lies between 1' and 2' (time 40 of Fig. 3.5), the time for exploitation may be ripe.

So far the concepts of "old, or current technologies" and "new technologies" have been introduced without explanation. The "older" or "current" technologies would be quite obvious. These are the ways a functional capability is or has been accomplished. The forecaster learns, hopefully, of "new technology" from the scientific and engineering communities. The forecaster must continuously probe into alternate means of accomplishing each capability of interest to his task and evaluate the potential of each suggested technology. By becoming aware of novel approaches, he establishes a position to exploit new findings or knowledge, no matter when it occurs.

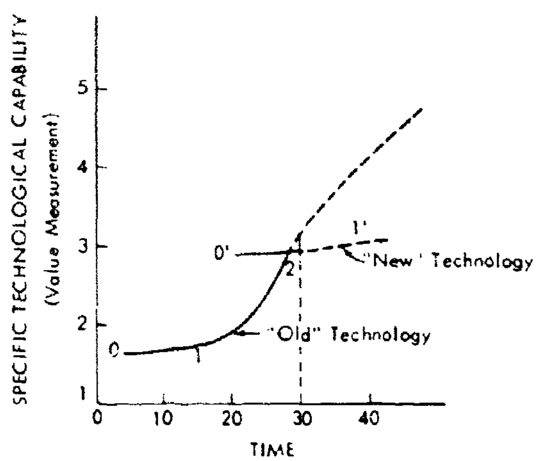

Figure 3.6. Extrapolation of Trend for "Newer" Technique as of Time 30

PARAMETRIC SENSITIVITY ANALYSIS

When the trend of one parameter is determined by that of two others, a sensitivity analysis is in order.

In a sensitivity analysis, the dependent parameter of interest is tested for sensitivity to other parameters, which may be random variations of nature, design variations open to choice, or technical limitations. These are varied over their likely, possible, or permissible ranges, and the consequent range in the dependent parameter is computed. The display of the computations may look something like Fig. 3.7. Here the performance, V, of a system at time, t, is expected to be at the point of the cross. However, V is sensitive to α, a technological parameter being changed by R&D projects, and to β, an operational parameter being changed by evolving operational context. The sensitivity of V is now exhibited as the asymmetrical egg. Under the assumption that the probability distributions are similar for the ranges of α and β shown, the egg takes this shape.

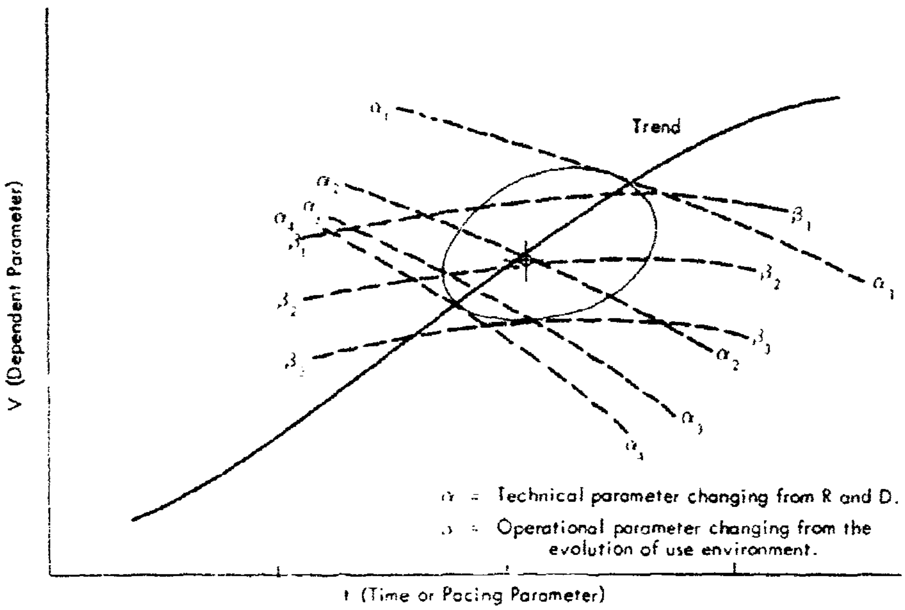

Figure 3.7 Uncertainty Expressed as Sensitivity to Variable Parameters

Some hypothetical examples of V, α, and β for several fields of technology are listed below:

<u>Medicine</u>

V - Doctors per casualty

α - Burn-shock reduction by pharmaceuticals

β - Nuclear or conventional war

VTOL

V - Payload per gross weight

α - Lift/drag for boundary layer techniques

β - Invulnerability assurance

Clothing

V - Hours in toxic environment

α - Absorption coefficient of synthetic fibers

β - Ambient temperature

Communications

V - Channel-years per satellite launch

α - Power rating of small power sources

β - Payload of available boosters

Section 5. TECHNIQUES FOR EXPRESSING TRENDS

TECHNIQUES

Words without pictures are as weak as pictures without words. In the first instance, the reader is asked to visualize what is spread out in rhetoric and probably exists in the mind of the writer. In the second instance, pictures imply a logic which may not be identical with that of the accompanying syntax. A technological forecast should be a proper combination of the new modes of expression.

Figure 3.8 depicts a time-dependent trend. The payload ratio of flying belts is shown as it is expected to increase in the future. Conventional fuel is a barrier at one level of performance and exotic fuels at another level of performance. The improvements between barriers are those expected in the usual history of applied science and engineering going from the demonstration of feasibility to the futility of incremental improvements. The figure implies that current new fuel research would break out in 1963. It also implies that between 1965 and 1970, competition will exist between the underdeveloped new configuration and the overdeveloped old configuration. The broad areas indicate the confidence interval. In this case real time is shown as the independent variable for progress, and this makes a certain amount of sense.

In other cases, the identification real time is less precise. Often the real times of occurrence of steps of progress are dependent on one or more factors (parameters or variables). Figure 3.9 depicts a parameter-dependent trend. The gal/day of desalinized ocean water is hard to put on a time scale of expected progress. Many factors affect this progress, two of which are the cost of power and the diffusion rates of membranes. These effects are not independent. Their joint occurrence would determine the performance characteristics of diffusion desalinization plants, but no one is confident in predicting the separate parameters as time-dependent trends.

The picturing of parameter-dependent trends is full of problems. In the first place, partial and contingent dependency is poorly represented graphically. For instance, the rule of combination of the partial effects of Y and Z on X is not necessarily that implied by the chart, namely, addition. There may be complex relations between diffusion rate and power in specific design applications because of such things as induced potentials. On the other hand, if X, Y,

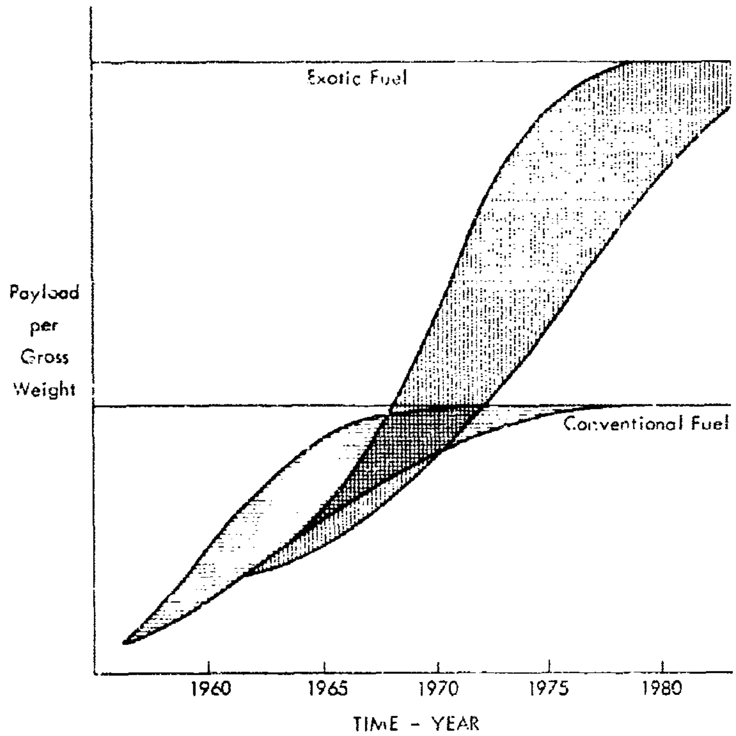

Figure 3.8. Time-Dependent Trend--
Payload Ratio of Flying Belts

and Z. are graphed together in a three-dimensional pictorial to account for this specific-design interaction, then the general nonspecific design direction of effects may be obscured. The specific functionally related curves are basic to systems design, whereas the trends are the engineeringly imprecise but directionally correct information for planning. The engineer cannot use what is useful to the planner and the planner cannot use what is useful to the engineer.

The problem here is not trivial. It bears on the whole issue of the feasibility of forecasting in terms of time and probability. Almost all forecasting, if taken seriously, involves parameter-dependent trends as elemental pieces. Time as an independent variable takes on increasingly the role of a modulus and not real time. Again, the correspondence between real and psychological probabilities in predicting R&D products is called into question. With little physical basis for making probability estimates, should the available physical elements be combined or should an overall estimate of probability be made by the forecaster? If the latter makes more sense, the forecaster's projections in probability terms can be logically combined by planners who are not predictors, but who deal with even larger aggregates and who need to know their probabilities.

A way to communicate the relationship of events without risking a precise time prediction is to describe and depict the human process in the quest for technological results. Figure 3.10 is an example of expressing trend as process in the acquisition and application of knowledge. High-vacuum technology is shown as progressing over the decades by innovations and adaptations arising from various other technologies. This figure could be elaborated to great detail without loss of its communications value, expecially if groups of blocks are color coded (e.g., inputs, devices, outputs, applications) and if the process arrows are coded for various meanings

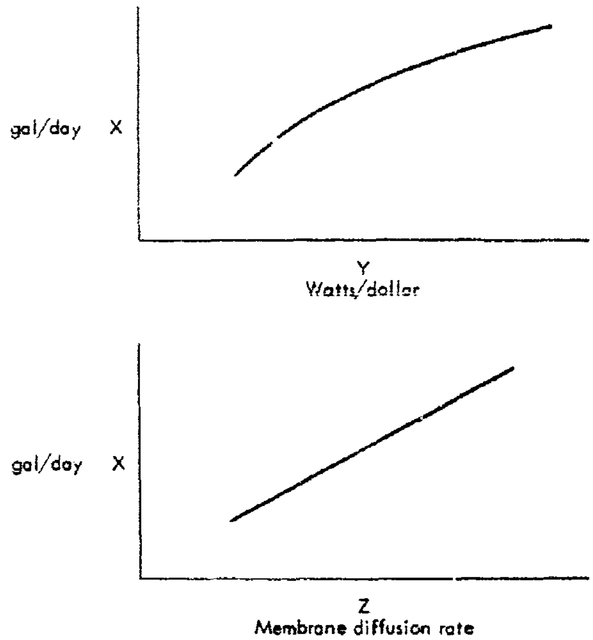

Figure 3.9. Parameter-Dependent Trend—Desalinization of Ocean Water

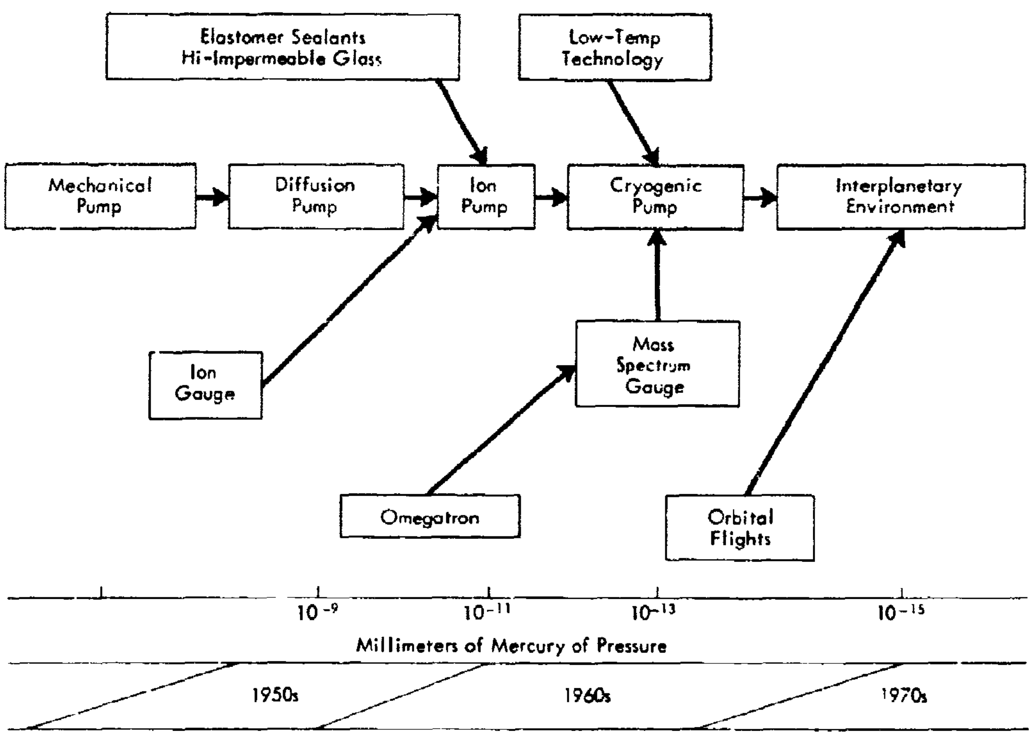

Figure 3.10. Trend Expressed as Process--High Vacuum Technology

(e.g., A begot B, A merged into B, etc.). The logic implied by blocks related by arrows so coded could be conjectured inputs and impacts of potential future technologies. For the product planner, blocks could be tapped off at different points in the process showing the effects on such things as feasibility of small fusion reactors, weight reduction in space vehicle structures, and high-performance cold electron tubes.

Large techno-military systems evolve over years. The trend in their configuration is rooted in the past and it helps the producer of the forecast as well as the user of the forecast to visualize the evolution. The forecaster is forced to see the big picture when adding novel detail, and the user gains a sober impression of the inertias inherent in growth and change. Figure 3.11 shows such a trend as evolution in the configuration of a system. The subject is the ground environment of air defense nets and the pictorial is quite schematic almost like the budding pattern of organic growth. Directions of systems growth which were abandoned or are expected to flourish temporarily, are depicted as buds which stop reproducing. The size and interfaces of buds can be used to imply the strength and sources of growth increments.

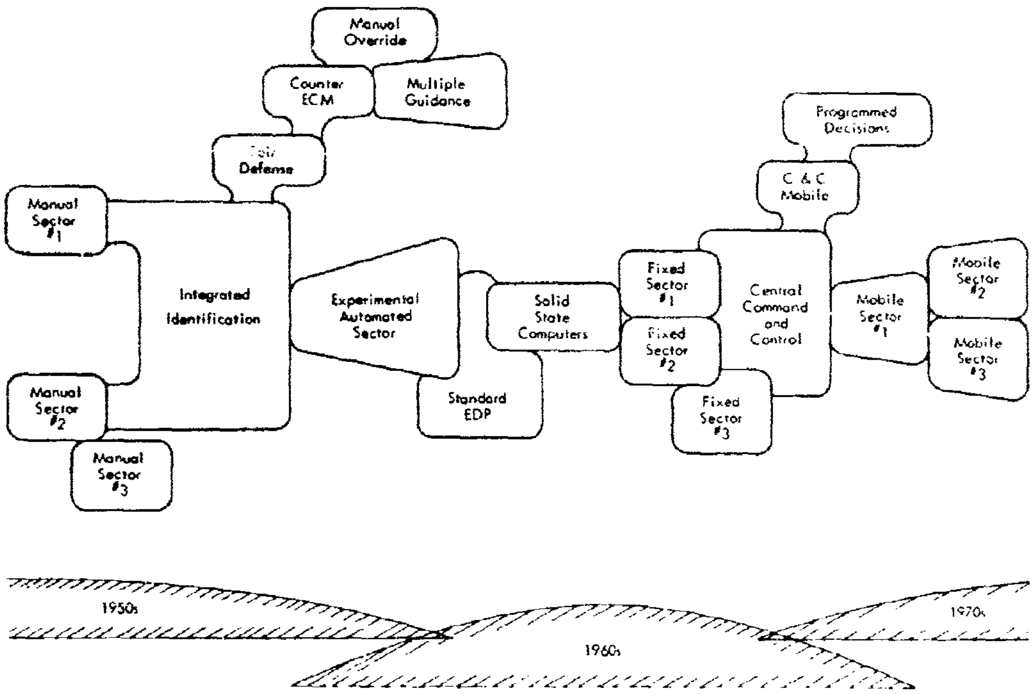

Figure 3.11. Trend Expressed as Evolution--Air Defense Ground Environment

Sometimes the operational objectives of technology can be identified and expressed fairly easily. When this is the case, the progress expected of technology can be illustrated as partial fulfillment of these objectives.

When trend is expressed as partial progress, the end-point should make technical and operational sense. If the goal is merely the completion of a project or program, the time-wise progress graph may make good reporting data for programmers and budgeteers, but not for forecasters and planners. The completion of a project may be essential to the success of a larger program, but the planner could hardly care less if such a project is twenty or ninety percent complete. Expected results are what he needs to know. (Of course, it would be a matter of concern if the cost of the program is not commensurate with results in terms of the technical/operational goal.)

Not all technical programs are easily defined in terms of objectives. However, with some thoughtful and analytical attention, it is likely that many technical programs can be converted from "percent progress" or "percent budget spent" to presentations of substantive goal-fulfillment. To do this, of course, requires the identification of the goal and its description in parameters which are directly relatable to the performance parameters of the end products of the technical program, which can be a painful exercise.

EXAMPLES OF TREND PRESENTATIONS*

The trend of a critical characteristic (in this case the thrust-to-weight ratio of lift engines) is shown in Fig. 3.12. Uncertainty (because of technology or funding limitations) is shown by the use of broad lines. The impact of new techniques (in this case, materials) is also shown.

The case of a development involving the projection of two critical parameters (in this instance, power gain bandwidth and system noise of solid-state amplifiers) is shown in Fig. 3.13.

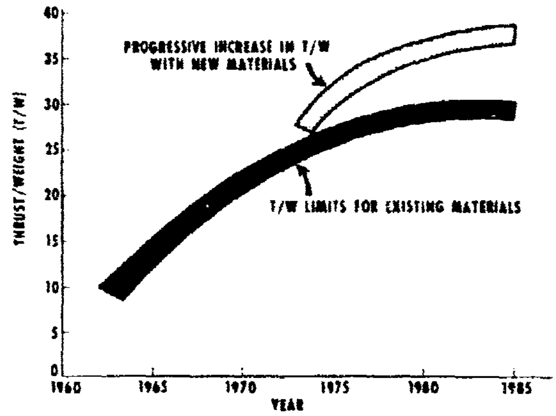

Figure 3.12. Trends in Thrust-to-Weight Ratio of Dependent Lift Engines

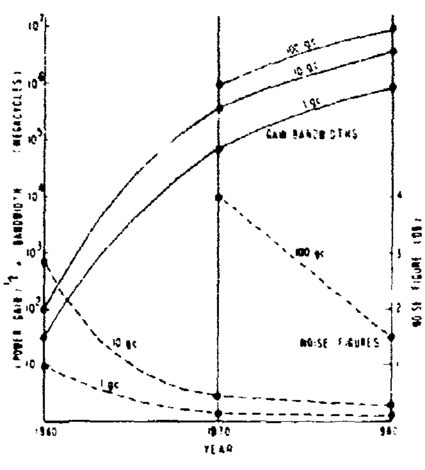

Figure 3.13. Projected Development of Solid-State Amplifiers

*Forecast data given herein are drawn largely from references (22) and (28) of Appendix E.

The projection of a critical characteristic in technology, in which specific milestones in research and development are identified, is shown in Fig. 3.15. The actual and anticipated gains in certain characteristics of air-cushion vehicles (ACV's) are reported.

> Air-cushion vehicles' performances, in terms of a factor of merit, are projected for a vehicle with a bare bottom and with a skirt and trunk system. Significant improvements in ACV performance have resulted from the development of skirts and flexible jet extensions. Aerodynamic problems associated with these developments have been largely resolved, but finding suitable materials for the air-cushion devices is a continuing problem.

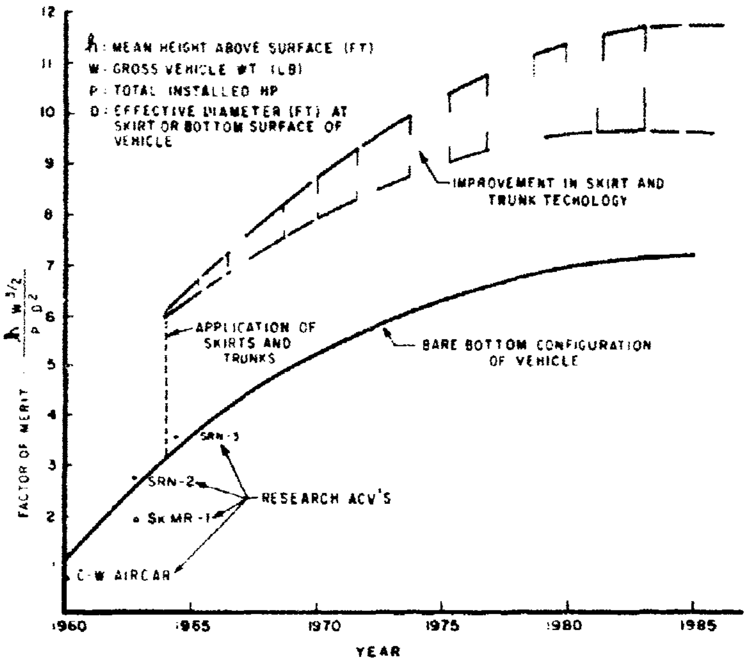

Figure 3.15. Air-Cushion Vehicle (ACV) Performance

Figure 3.16 shows performance characteristics of microwave tubes over the past 25 years and as projected through the next 15 years.

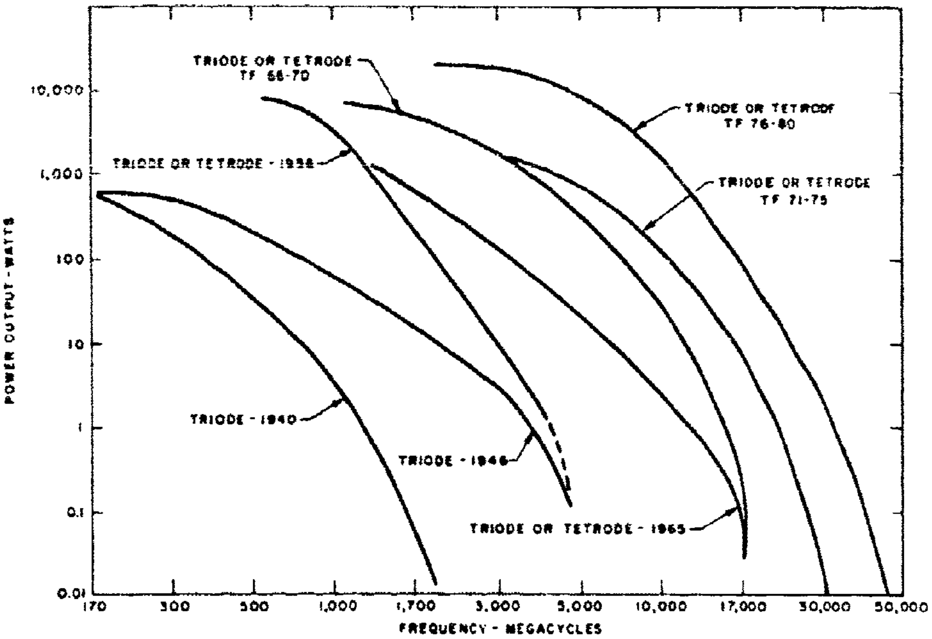

Figure 3.16. Progress in Capacities of a Single Tube

The projection of a critical characteristic in terms of other constraining parameters is shown in Fig. 3.17.

> In order to resist the intense temperatures, high pressures, shear forces, corrosion, and erosion of exhaust gases, the uncooled nozzle on the solid-propelled rocket has, of necessity, been undesirably heavy. The flame temperature of present-day exhaust products ranges between 5700°F and 5900°F (Fig. 3.17). As of the time of the preparation of the forecast, these temperatures were soon expected to exceed 6300°F, and would approach 7000°F by 1970, requiring the development of nozzles whose underlying principle of functioning is by other than heat-sink methods. This can be accomplished by using the highly refractory metals, hafnium, tantalum, and tantalum-zirconium alloys which have melting points around 7000°F.

The trend of a critical parameter may also be presented on a bar graph, as shown in Fig. 3.18.

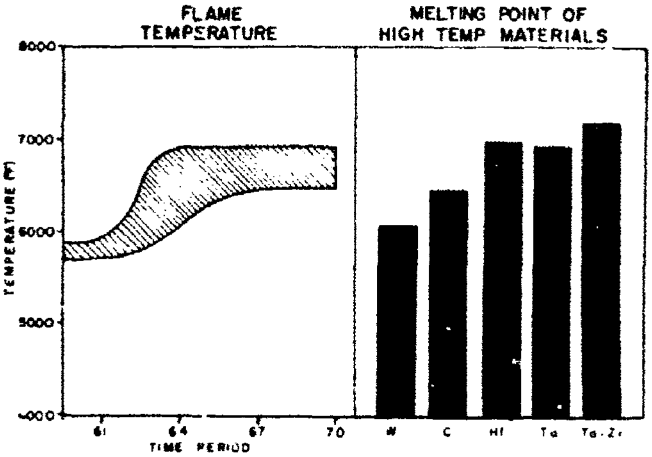

Figure 3.17. Projected Propellant Flame Temperature

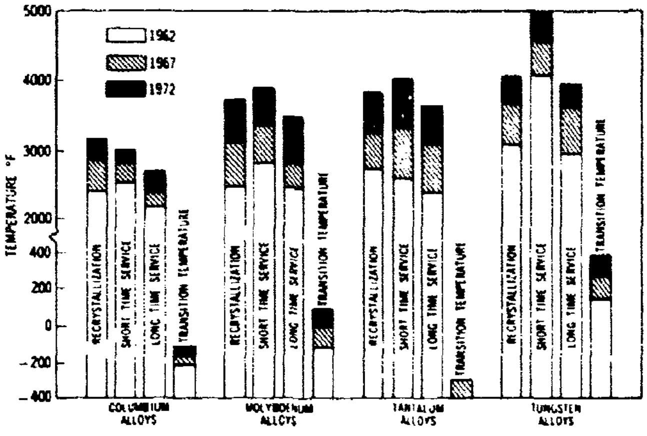

Figure 3.18. Refractory Metal Alloys

In some areas of investigation it becomes necessary to define requirements for research and development in the several elements of the area under consideration. It is possible to project the state-of-the-art in the various disciplinary areas and to estimate their relative importance during the forecast period in terms of operational requirements. From these two trends, it is then possible to establish research requirements and associated resource (personnel, funding) needs during the period under examination.

> For example, Fig. 3.22 looked to defining a desirable Nuclear Weapons Effects research program for the projection of aircraft and air crew in 1962 and following years assuming an extended moratorium on atmospheric nuclear weapons effects tests. Figure 3.23 shows the relative importance trends of nuclear weapons effects and Fig. 3.24, indicating relative research requirements (RR), combines relative importance (RI) and predictability (P) in terms of percent of total requirements as follows:

$$RR = \frac{RI \times (1 - P)}{\Sigma[RI \times (1 - P)]} \times 100$$

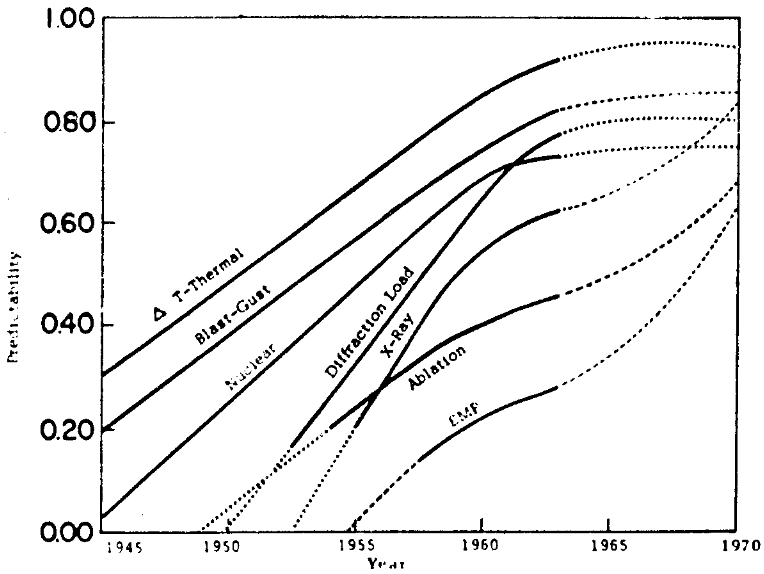

Figure 3.22. Predictability Trends

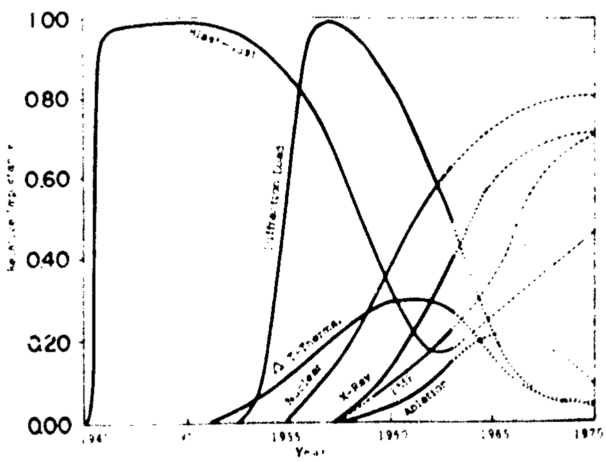

Figure 3.23. Relative Importance Trends

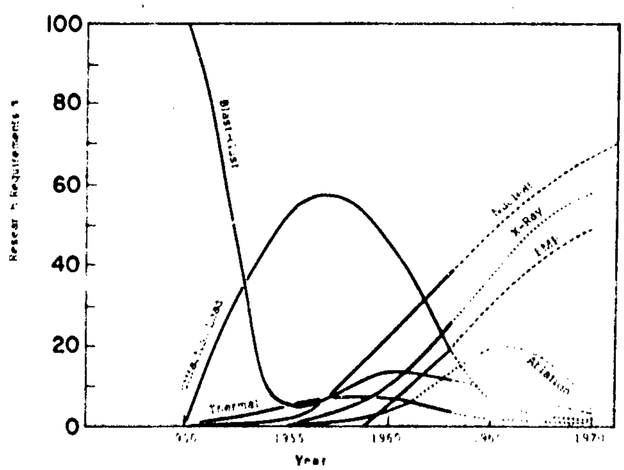

Figure 3.24. Research Requirement Trends

CHAPTER 4

PART I — SCIENTIFIC OPPORTUNITIES

Section 1. INTRODUCTION

Scientific knowledge is a basis for the prediction of outcomes. It is the store of knowledge essential for rational support of cause and effect relationships, which in turn are the substance of planning. The forecast of Scientific Opportunities is intended to provide a data bank of selected "outcome" predictions from the total store of scientific knowledge. The forecast is an information source for planners designed to be:

a. Useful in retrieving scientific knowledge significantly relevant to naval technology, and

b. Useful in the assessment and orientation of naval research programs.

The Scientific Opportunities forecast thus has the objective of providing management with a tool for the planning and utilization of Navy-relevant science and technology.

Since, by definition, it is not possible explicitly to forecast basic research, some clarification of the inclusion of research in the Navy Technological Forecast, and indeed as a Navy-funded program, is in order.

An OPNAV definition of research, for Navy planning purposes, is as follows:*

"Research - Includes all effort directed toward increased knowledge of natural phenomena and environment and efforts directed toward the solution of problems in the physical, behavioral and social sciences. It would thus, by definition, include all basic research and, in addition, that applied research which is directed toward the expansion of knowledge in various scientific areas. It does not include efforts directed to prove the feasibility of solutions of problems of immediate military importance or time-oriented investigations and developments."

The RDT&E Management Guide† further defines basic research as:

"Research directed toward the increase of knowledge in science, the primary aim of the investigator being a fuller knowledge or understanding of the subject under study,"

and Applied Research as:

"The application of knowledge, material and/or techniques directed toward a solution to an existent or anticipated military requirement."

ONR has still another and a special definition for Naval Research:

"To encourage, support and conduct systematic and exploratory research in basic and applied science which contributes information leading to discoveries of potential importance to new materials, equipment and working principles, or to new concepts in military operations and philosophy."‡

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*OPNAVINST 3900.8C.
†Department of the Navy, "RDT&E Management Guide," Vol. II.
‡ONRINST 3910.2A.

Thus, naval research is both basic and applied and will tend to emphasize scientific areas that can lead to the advance of military technology.

It is evident from the above definitions that the gray area merging naval research (Program 6.1) with exploratory development (Program 6.2) will be very broad. This overlap is a practical fact of life that is receiving increased recognition in Navy Department R&D planning.

A useful military system is comprised of particular arrangements of technical building blocks that have evolved from a broad base of scientific knowledge.

Figure 4.1 is a simple illustration of the two-way path between systems and science. The standard approach is to describe a conceptual system on the basis of a predefined mission and need; assess the capability of technology to provide the required performance; isolate and define engineering and scientific deficiencies; and direct effort toward resolution of these. This is an essential routine in the business of all "projects," and a primary basis for the selection of appropriate areas for exploratory development and research. The scientist, in particular, may point out two anomalies:

a. The base for selected areas of militarily useful scientific knowledge, while finite, will be very broad even when it is premised upon predefined systems requirements.

b. Truly innovative and effective systems are often not conceived on the basis of predefined need. They become feasible and needed because of scientific advances that were not initially systems oriented (i.e., research).

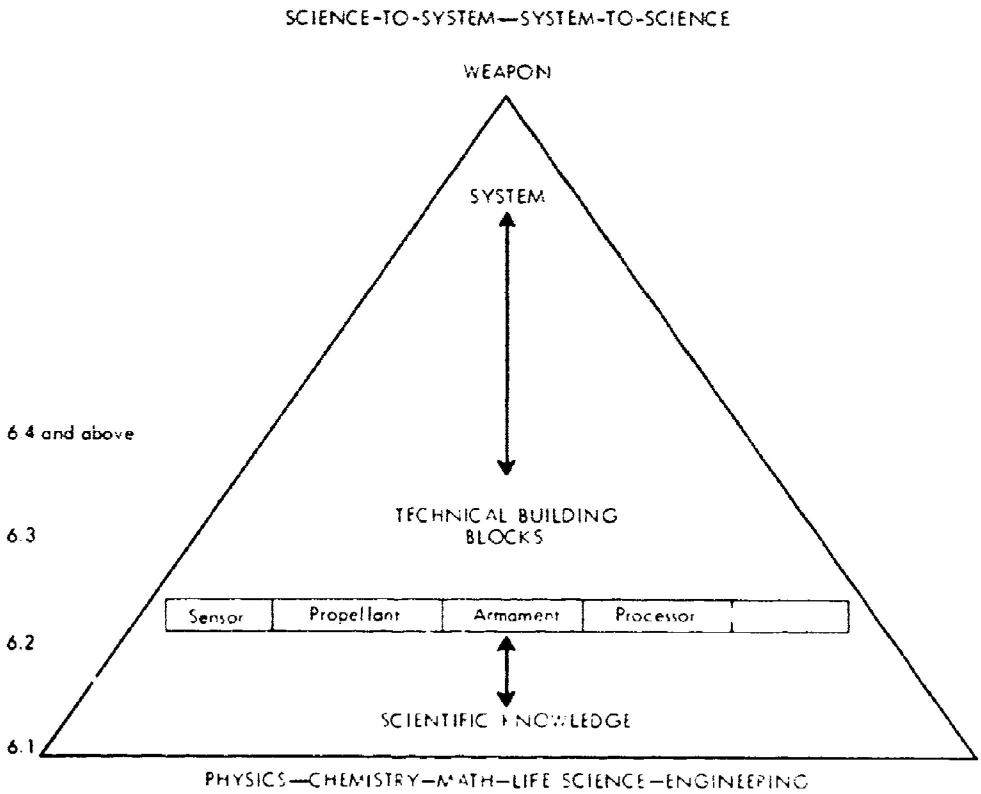


Figure 4.1

The case for DOD-supported research assumes that both paths of Fig. 4.1 (science-to-system and system-to-science) must be considered in the delimiting of scientific areas of military concern. This dual approach concept has been followed in the DOD formal delineation of "Defense Research Sciences" and (for the Navy) of Naval Research Requirements.

The first tasks in planning for a forecast of Scientific Opportunities were to define and to categorize naval research. Definitions and a philosophy for categorization are outlined above. In 1961, the Office of Naval Research published a descriptive set of 81 naval research requirements. It is in order to update these, as required, and to make them compatible with the RDT&E fiscal and planning structure, i.e., with the four areas and fourteen elements of the "Defense Research Science." Models for accomplishing this are provided in later sections.

A proposed format for the "Scientific Opportunities" part will separately treat each of the above-mentioned categories (naval research requirements). For each category there will be prepared a FORECAST section and an APPRAISAL section. These will be described in greater detail.

The FORECAST section will cover:

a. Background
b. Present Status
c. Forecast

The FORECAST section intends selectively to provide broad-scope coverage of those aspects of the category considered to be important from the point(s) of view of Navy relevance and/or scientific advance. Source materials are not limited to Navy-sponsored research, but rather include all pertinent efforts in the category field.

The APPRAISAL section is an appraisal or interpretation of the first in terms of naval and scientific significance. There are two alternative criteria for the selection of items in the APPRAISAL section. Each included item should be significant in terms of:

Scientific advance potential, and/or
Navy and Marine Corps application potential.

This chapter will provide a listing of categories considered appropriate for the Navy Department forecast which listing is compatible with the RDT&E fiscal and management structure; and a detailed format generally but incompletely displaying recommended forecast content. The category selected for format display is "Solid State Physics." The materials presented do not constitute a complete model for that area.

Section 2. CATEGORIES

The Department of Defense has catalogued Defense Research Sciences into four areas which are further divided into fourteen elements. Naval research categories are described as "Naval Research Requirements" in ONRINST 3910.2A of 1 September 1961. There are 81 of these requirements. In order to make the research category listing compatible with the DOD fiscal and planning structure, it seemed desirable to determine whether the categories could sensibly be arranged as subdivisions of the fourteen Defense Research Science Elements.

The Office of Naval Research is currently revising the naval research category listing and their descriptions. A category revision should result in both the updating of Naval Research Requirements (Areas) and the establishment of compatibility with Defense Research Sciences. Models for such a revision have been prepared and are presented in Appendix A. For these models, the revised categories of Naval Research Requirements (Areas) are listed under appropriate Defense Research Science Elements. Brief descriptions of each category in terms of scope and content are provided in Appendix A. These categories reflect initial efforts of the NRL Research Program Office leading toward a definition of areas of Naval Research in a compatible format.

Section 3. FORMAT

CONTENTS OF FORECAST

The following note provides suggested guidelines to those responsible for the preparation of the Scientific Opportunities Forecast.

Navy Technological Forecasts will reference materials principally intended for use as management tools for planners of R&D programs and for planners of advanced military systems for the operational Navy. These two audiences have different, although related, forecast information requirements. The R&D planner needs sound basis for introducing new areas of investigation and for the shifting emphasis in on-going programs. The military systems planner is concerned with the technical feasibility of performance that can be operationally useful in a particular time frame. Neither audience would go to the Forecasts for detailed information concerning a particular physical phenomenon. The expert specialist and the literature will always be better reference sources. The preparer of forecast materials will thus recognize his task to be the compilation of a condensed document, not a text. Further, the audience for the forecast is management, not the learned scientist. And, finally, the objective of the forecast is to provide information in a succinct form that can be useful in the direction, control, and application of naval science programs. The preparation and use of forecast materials is designed to enhance dialog between the Navy scientific and operational communities in a mutual influence process.

Basic and applied research are somewhat remote from fleet utilization relative to advanced development. A suggested filtering process for selection of material to be presented in the "Scientific Opportunities" section is the requirement of a "yes" answer to either or both of the following questions:

a. Are the data needed in order to describe a significant potential advance in scientific knowledge?

b. Are the data probably useful in support of a Navy technological need?

The latter question attempts partially to apply the science-to-system philosophy described in the introduction. It is, of course, particularly important that scientific advances of a basic nature be identified if the probability of useful Navy application is high. The Navy Exploratory Development program will be enriched by this kind of output from the "Scientific Opportunities" forecast.

The proposed format outline, amplified in the next Section, is as follows:

A.	Background	Forecast Section
B.	Present Status	
C.	Forecast	
D.	Naval and Scientific Significance Potential High Pay-Off Areas Areas of Diminishing Returns	Appraisal Section
E.	Associated R&D Organizations	Supporting Data
F.	References	

The proposed approach for the naval forecast of Scientific Opportunities begins with selection of categories and their indexing as elements of the Defense Research Sciences (see Section 2 of this chapter). Each category is treated against a standard format comprised of a data base and forecast, followed by a focusing upon selected materials from the base in terms of significance to scientific advance and to Navy relevance. The TF (technical forecast) categories will be subdivisions of Naval Research Requirements (Areas) (ONRINST 3910.2A of 1 September 1961).

FORECAST SECTION

The proposed standard format for the Forecast section includes the following items:

Background. A brief of highlights of the evolution with emphasis on relevance to Navy technological needs. The background statement provides perspective in digest form.

Present Status. A display of the present state-of-the-art of the category as a basis for forecast projections. Selected coverage will be limited to those items of particular scientific interest and/or Navy relevance. Generalities should be avoided in favor of a quantitative expression of achieved parametric limits.

Forecast. A projection of up to, but not limited to, 10 years or more of anticipated advances for the items selected. The projection is to be quantitative where practicable. It anticipates and identifies appropriate changes in emphasis and resource utilization over present effort. The level of confidence in the projection validity is displayed or given a numeric value. Parametric forecasts are preferred over end-item or special-purpose device composite performance estimates. Content is principally graphic display with brief supporting and qualifying narrative.

APPRAISAL SECTION

The Appraisal Section, which may be published separately, is an assessment in terms of:

Naval and Scientific Significance. This constitutes an expert appraisal, from the point of view of the Navy scientist, of selected items in the category field. Factors are assessed in regard to their potential worth to material advance in scientific knowledge, and/or toward fulfillment of Navy Dept. technical needs. Since the Scientific Opportunities forecast has utility primarily as an aid to research and development planning, it should provide, in particular, criteria that can support:

a. Re-orientation, or change in emphasis, for areas of Navy scientific investigation

b. Re-orientation of scientific knowledge toward applied or exploratory development phases of investigation leading ultimately to fleet utilization

The deliberate identification of potential high pay-off areas (as well as those of diminishing returns) will serve selectively to focus attention upon significant items. In particular, new and advanced concepts are to be identified that show unusual promise, those that can lead to marked gains in science or in naval technology.

The effective exploitation of new discoveries and developments arising from research programs will require that they be presented in terms of possible application to operationally useful naval systems. The intermediate element in the science-technology-systems route is, of course, exploratory development. It is, therefore, an objective of the Appraisal Section to relate research findings directly to Exploratory Development Goals.

In the RDT&E management structure, research endeavor (RDT&E category 6.1) leads to exploratory development (RDT&E category 6.2) in the sequence toward military application. Fiscal planning documents categorize exploratory development effort in terms of "elements." These are generally related to military functions or technologies. Indications of the relevance of relatively basic scientific advances to Navy-Marine Corps technological needs has been identified as a burden of the forecast of Scientific Opportunities. Such relevance can most directly be charted against predefined goals of naval technology. These goals are in the process of being defined by the Exploratory Development Division of NAVMAT.

The Technological Capabilities section of this report catalogs technologies (see Appendix B), and functions of Navy interest as follows:

Section 1 - Engineering Technologies

1.1 Materials Technology
1.2 Fluid Dynamics
1.3 Environment

1.4 Acoustics
1.5 Electromagnetics
1.6 Information Processing and Presentation

Section 2 - Surveillance and Target Acquisition

Section 3 - Communications

Section 4 - Navigation

Section 5 - Power Technology

Section 6 - Weapons Technology

Section 7 - Vehicles/Installations

Section 8 - Countermeasures

Section 9 - Supporting Technologies

9.1 Logistics
9.2 Biological and Behavioral Technologies

Section 10 - Space Technology

The above "Sections" are further subdivided so as to exhibit proposed Exploratory Development Elements and associated current Exploratory Development Requirements. For the purpose of showing the Navy-Marine Corps relevance of potentially high pay-off "Scientific Opportunities," the above sections will be used as relevance categories.

Those areas showing possible low pay-off should also be called out and appraised in terms of:

a. High-risk versus limited potential gain

b. Remote relevance to Navy-Marine Corps problems and projects

c. A projection of diminishing returns due to uncooperative natural laws or other predictable dead-ends.

SUPPORTING DATA

Associated R&D Organizations. Organizations making important contributions to the category discipline are called out to suggest sources of more detailed technical data than are provided in the forecast. The names of outstanding experts, particularly those in in-house laboratories, can be provided for the same purpose.

References. Selected, particularly useful references are desired, as opposed to an exhaustive list. References from which forecast material has been derived will be included.

The individual and/or organization responsible for the validity of the forecast will be indicated for each category.

Section 4. SAMPLE FORECASTS

Guidelines and ground rules for the compilation of forecast materials are provided in Section 3, Format. The quality and credibility of the forecast will vary directly with the competence and extent of effort of those who prepare it. The preliminary materials presented in the sample are not adequate and in some instances not necessarily credible. The sample would be more representative had it been prepared by personnel knowledgeable in the field who had adequate time to prepare it. The intent of the sample is to provide an example sufficiently related to life as to be useful to the Solid State scientists who would prepare the final material. Where the foregoing guidelines and the following example are inconsistent, the guideline instructions should prevail.

SAMPLE FORECAST

(Preliminary)

R001 02 SOLID STATE PHYSICS

Solid state physics is the study of physical properties of solids and interpretation of these properties in terms of quantum and band theory, thereby providing stronger foundations for metallurgy, optics, electronics, and other applied sciences.

SOLID STATE PHYSICS

Principal Subdivisions

Theory of Solids

Synthesis, Growth, and Structural Characterization of Solids

Mechanical and Thermal Phenomena in Solids

Electronic, Magnetic, and Optical Phenomena in Solids

Interaction and Radiation Effects in Solids

R001 02 SOLID STATE PHYSICS

CONTENTS

A. BACKGROUND

Solid state physics is developing a better understanding of the properties of matter and an improved capability for materials synthesis. Research in this area is leading, among other things, to both reduction in size and controlled versatility in capabilities of electronic devices. Specific examples of Navy interest are:

- More powerful, yet smaller magnets
- Smaller, more versatile and more reliable electronic components and composites
- Electro-optical sensing devices of remarkably advanced capability
- Controlled use of coherent radiation (as in lasers) for the transmission of energy and intelligence
- Controlled crystal growth capability

1. Theory of Solids

a. Areas of particular and continuing interest concern imperfections in solids and the existence of and transitions to ordered states.

2. Synthesis, Growth, and Structural Characterization of Solids

a. Crystal Growth and Characterization of Electromagnetic Materials

Goals of research in this field include:

(1) A better understanding of the variables and parameters that influence the nucleation, growth, and chemical and structural perfection of single crystals of electromagnetic materials

(2) Characterization techniques such as X-ray, neutron, and electron diffraction for the precise determination of the electronic properties of these materials

(3) New purification techniques for the preparation of purer semiconductor, optical, and magnetic materials

(4) Advances in analytic techniques for the determination of purity, structure, and electromagnetic character of these materials

3. Mechanical and Thermal Phenomena in Solids

a.

b.

c.

4. Electronic, Magnetic, and Optical Phenomena in Solids

a. Solid State Laser Materials

A major objective of R&D in this area is to improve both spatial and temporal coherence of high average power. Specifically, objectives include:

(1) Attainment of laser system effectiveness of 5% to 10% efficiency

(2) Investigation of ions which have particularly attractive fluorescence wavelengths (as terbium, erbium, and holmium)

(3) Study of multiple doping for purposes of sensitized fluorescence and radiative relegation to metastables of interest

(4) Theoretical assessment of the potential of actinide ions particularly from the viewpoint of efficiency, practicality, and economy

5. Interaction and Radiation Effects in Solids

a. Radiation Effects on Electronic Device Materials

Techniques are developed for minimizing deleterious effects on device materials to obtain the knowledge necessary to predict accurately these effects and to identify promising new materials. The object is to provide electromagnetic device materials with improved radiation tolerance and to predict accurately changes in critical properties.

6. Applied Goals

a. The applied results of solid state physics research and development will lead to or produce techniques, electron devices, and early circuit design concepts that will support Naval Exploratory Development Goals in the areas of

1.1 Materials Technology
1.4 Acoustics
1.5 Electromagnetics

and functional goals in the areas of

2.0 Surveillance and Target Acquisition
3.0 Communications
4.0 Navigation
5.0 Power Technology
6.0 Weapons Technology
7.0 Vehicles/Installations
8.0 Countermeasures
10.0 Space Technology

B. PRESENT STATUS

[Section A. BACKGROUND divided Solid State Physics into five principal subdisciplines to establish some degree of order in describing the scope and content of the field. The following sections do not repeat this order, although such a procedure may be found to be desirable in the final forecasts. Instead, this first effort is an attempt to identify only significant items. Some items may not be well chosen. They should, however, illustrate an intent to limit content to items of particular scientific interest or Navy relevance. They are obviously incomplete.]

1. Basic Studies of Particular Promise

a. Impurities and Imperfections

(1) Electronic excitations due to shallow charged substitutional impurities in semiconductors

(2) Deep impurities in a semiconductor

b. Transitional and Ordered States

(1) Diffusion of interstitial atoms and vacancies

(2) The nature of surfaces and the complex processes that take place in these

(3) In the area of ordered phases and phase transitions, problems of ferromagnetism, ferroelectricity, superconductivity, and structural changes such as melting

(4) Little understood presently but of great potential importance is the transition to a disordered phase under particular conditions of temperature, pressure, magnetic field, etc.

c. Surface Phenomena

Understanding of surface phenomena will advance with controlled production of crystals of desired characteristics, in controlled catalysis, and even in the investigation of substrate effect in biological systems.

The role of crystal planes in interactions will be better understood and controlled with improved methods of obtaining clean surfaces.

d. Phase Transition

An increase of future efforts in this area may be expected. The principal barrier is capability of observation on a microstructure scale. This difficulty is unlikely to be completely overcome within the next 20 years.

2. Present Status of Selected Solid State Device Research Results

a. VHF Silicon Transistors (Operated as Class C common emitter amplifiers)

Frequency (Mc)	Power Output (watts)	Power Gain (db)	Efficiency (%)
1	100	12	70
10	100	10	65
100	70	8	65
500	20	5	30
1000	2	5	15
2000	0.75	7	10

Noise figure of small signal transistors for receiver use in the 100 to 500 megacycles range is in the order of 2.5 to 4.5 db and about 8 db at one gigacycle.

b. Digital Integrated Circuits

The 1966 state-of-art for digital integrated circuits is displayed in Fig. 4.2a. Evolution and projection of component density, reliability, and cost are shown in Fig. 4.2b.

c. Lasers

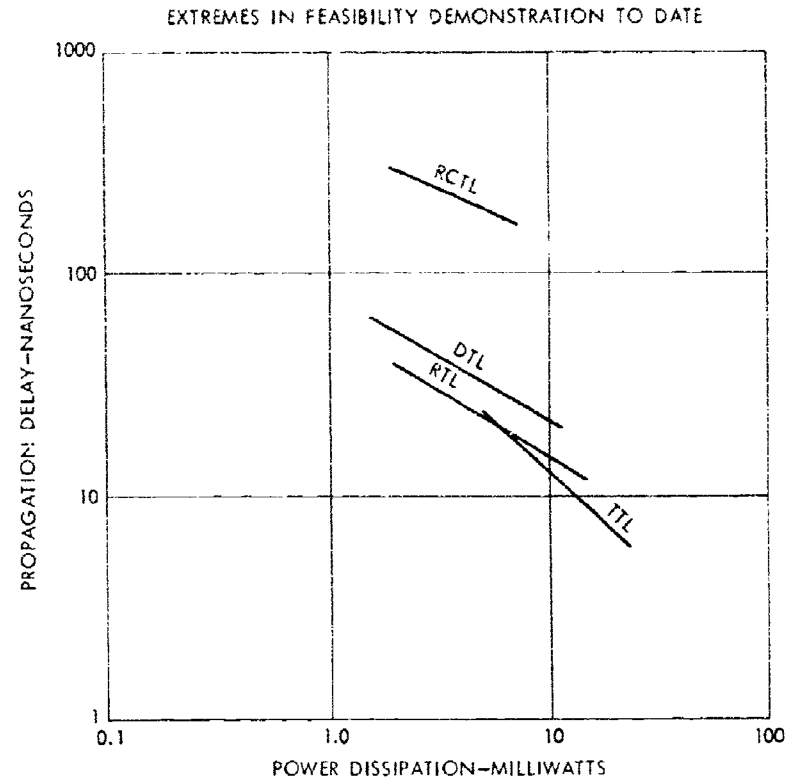
(1) Gaseous lasers

Gas	Power	Wavelength	Tube Size
HeNe	100 milliwatts	6328 Angstroms	1 meter
HeXe	3 milliwatts	3.5 microns	1 meter
Argon	5 watts	Blue-Green	1 meter
$Co-N_2$	16 watts	10.6 microns	2 meter (4% ef.)

(2) Semiconductor Lasers

Groups II-VI, III-V, and IV-VI compounds have demonstrated laser action. Output wavelengths range from 0.67 micron in GaAsP to 8.5 microns in PbSe. Ten watts CW power has been demonstrated at 30 K and 100 watts pulsed power at room temperature. Pressure tuning capability has been demonstrated with PbSe from 7 to 10 microns.

SAMPLE FORECAST



Code: R = Resistor C = Capacitor D = Diode T = Transistor L = Logic

SOURCE: DDR&E Advisory Group on Electron Devices, 14 April 1966

Figure 4.2a. State-of-Art Digital Integrated Circuits

C. FORECAST

1. New Materials

a. Superconductivity Materials

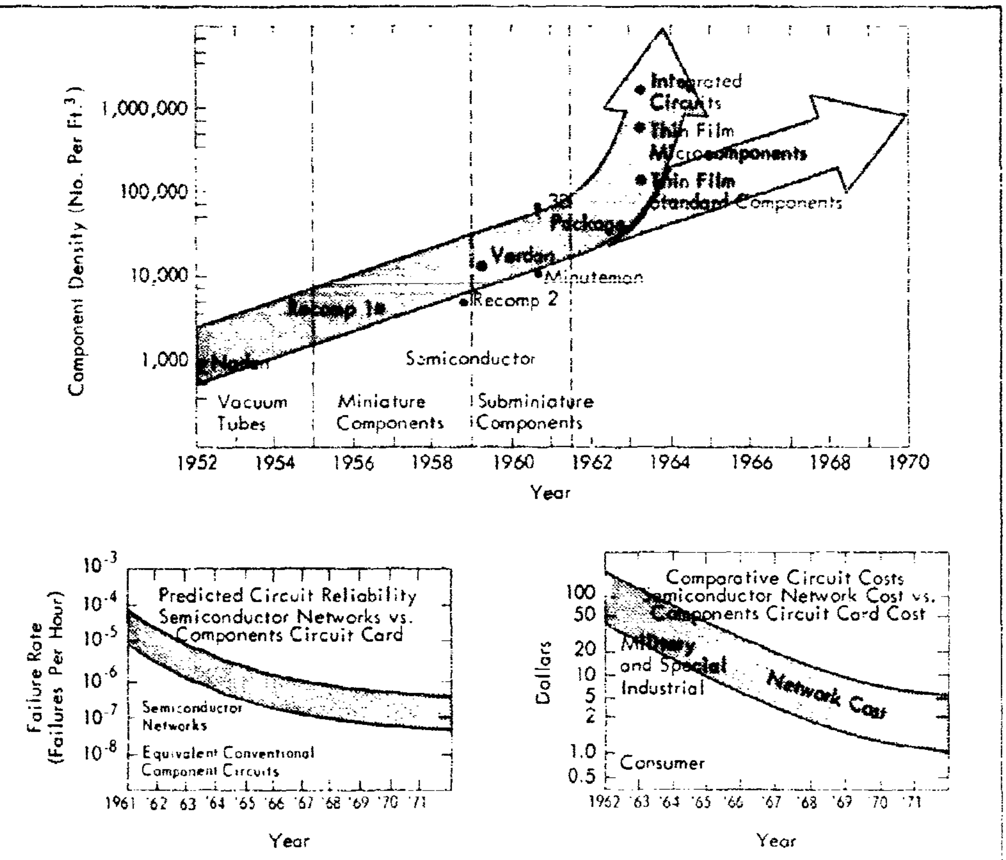
The study of alternative mechanisms for superconductivity may result in new materials highly useful at low temperatures.

b. Materials for Special Devices

Present state-of-art material developments have produced the transistor, the silicon controlled rectifier, the junction light emitter, the acoustic amplifier, Gunn effect generators, and bulk limiters. New materials of equally exciting application in sensors and electronic control can be anticipated.

c. Crystal Growth and Characterization of Electromagnetic Materials

The knowledge of detailed arrangements of magnetic dopants, rare earth garnet structure materials, and single and double dopants in host lattice is leading



SOURCE: Air Force Systems Command "Integrated Circuits Come of Age"

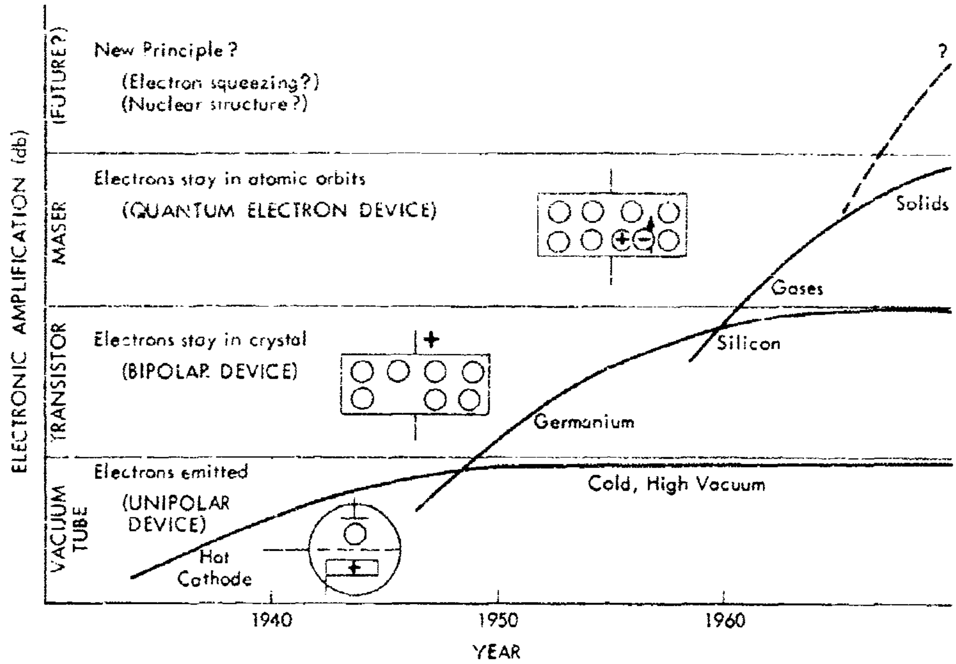
Figure 4.2b. Component Density, Circuit Reliability, and Cost Status and Trends

to improved device concepts based upon the control and use of quantum mechanical energy states.

Improvements in the purity of electronic materials and the increase in the variety of materials having useful electronic applications (for example, see Fig. 4.3), has created a demand for more sensitive, faster, and cheaper analytical techniques. The most sensitive analytical measurements are being made in emission spectrography and mass spectrometry. Improvements are being made in emission spectrography which indicate the feasibility of sensitivities of a part per billion or better. Neutron activation analyses is the most sensitive analytical technique available. Sensitivity of one part in 10^{11} has been achieved for a limited number of elements. Application of gamma ray spectroscopy shows great promise for reducing time and cost in the neutron activation analyses technique.

2. Application of Theory

a. Generation, control and use of coherent radiation is one of the most promising areas of solid state investigation. Its greatest applied utility will be in intelligence



SOURCE: "Technological Forecasting," Army Research Office

Figure 4.3. Electronic Amplification as a Function of Time and Technique

transfer with the modulation of sources, and as low noise amplifiers. Lasers tunable (Fig. 4.4) over a limited frequency range will be available. This availability at optical and longer wavelengths should provide impetus for spectroscopy.

b. The ultimate in miniaturization is direct use of individual molecules as electronic circuit elements, or for information storage. While this ultimate is not predictably feasible, there is tremendous room for advance.

c. Superconducting magnets with fields up to 70,000 gauss have recently been developed. New materials with higher critical magnetic fields will be found making still stronger magnets available (Fig. 4.5).

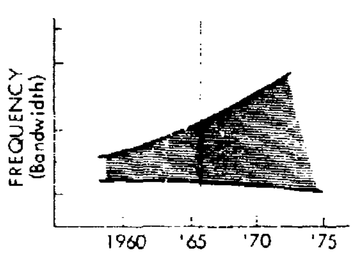


Figure 4.4. Coherent Radiation Tunability

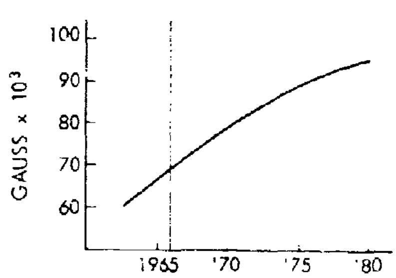


Figure 4.5. Superconducting Magnet Field Strength

d. Neutral particle beams will be developed within the next 20 years with resultant clearer understanding of the chemical kinetics of surfaces.

e. Control of phase transitions on the microscale will lead to new materials of exciting utility. Ability to store information, for example, may be increased by a factor of 10^6.

f. Investigation of materials at extremely high pressures (possibly up to 10^6 atmospheres) will give new insights into the constitution of matter and possibly new forms of matter.

g. Ultra-high vacuum (10^{-15} torr) will give new meaning to "clean" surfaces, making it possible to produce a more completely predetermined interaction.

h. Low temperature capability. Although temperatures as low as 0.1°K are now available in small volumes, advances in technique in the next 20 years will allow us to reach temperatures of 0.00001°K as shown in Fig. 4.6. With this capability, currently unpredictable properties of materials due to phase transitions will be better understood.

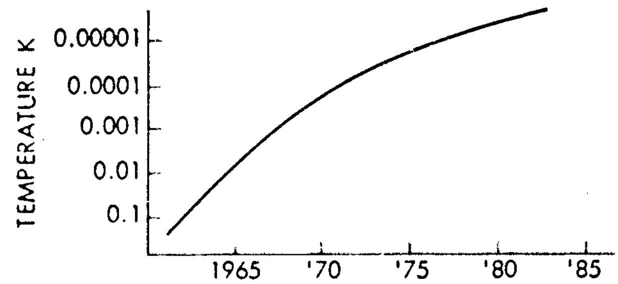


Figure 4.6. Low-Temperature Capability

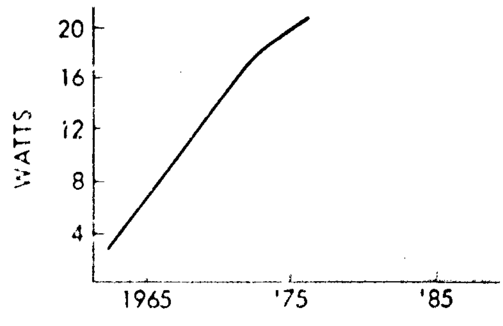


Figure 4.7. Coherent Radiation CW Power (Argon Ion Laser)

i. Crystal growth and characterization. The growth of single crystals of higher purity and perfection lies in a better understanding of the thermodynamic properties and a detailed phase-diagram of electronic materials. Relevant are investigations of thermal fusion, dissociation and recombination of polyatomic gas, and ultrahigh pressure-temperature. Improvements in electrokinetic methods such as electrolysis, electrophoresis, and electro-osmosis may meet the demands for increased purity. Void type zoning techniques may be made into a continuous system for the synthesis of high purity materials.

j. Radiation effects. The possibility of minimizing radiation effects caused by atomic displacements in silicon and related device materials by doping with suitable elements appears promising. Improved accuracy and control can be expected by continued study of displacement mechanisms and defect structures. The ultimate attainable in radiation-hardened materials cannot be reasonably estimated in the absence of more complete theoretical and experimental data; however, significant improvement can be expected. System hardening will be achieved mainly through improvements in materials, device structures, geometry, and selection.

k. Gaseous lasers. For example, the argon ion laser can be expected within 5-10 years to produce 20 watts in a multispectral line using a 1-meter tube-length source (Fig. 4.7).

CHAPTER 5

PART II — TECHNOLOGICAL CAPABILITIES

Section 1. INTRODUCTION

USES

A technological forecast in Technological Capabilities constitutes part of the research and development management program which relates the individual task in Exploratory Development to the operational performance to which it is directed. Since Exploratory Development is not a commitment to a system concept but rather an attempt to provide technical data on which to base trade-off analysis prior to Engineering Development, the span over which parameters should be varied during experimentation is potentially large. The technological forecast can assist in establishing the scientific technological base on which Goals for Exploratory Development can be developed, consistent with projected threat, strategy, and tactics considerations.

When more than one function contributes to an end-item development, a reasonable forecast can be employed to determine the relative burden on the projected state-of-the-art in each contributing area. A good forecast can also be used to identify technological areas particularly sensitive to development efforts. A moderate improvement in some technical areas could have a high impact on operational success, whereas a large technical gain in other areas may not improve an operational capability. Thus, forecasting should have a significant influence on R&D planning.

A technological forecasting program provides the Navy's technical community the opportunity to lead in the development of new capabilities for the operating forces. The forecast by providing unsolicited technical capabilities can influence changes in strategies and tactics and can promote development of innovative operational techniques or stated operational requirements.

A technological forecast will assist in specifying parameters for Exploratory Development Goals in instances in which trade-offs between functional capabilities exist, or in which the effect of environmental variations on operational capability must be considered.

A good technological forecast will identify areas in which component developments are compatible or augment one another. The forecast provides a means for direct communication among workers in the more technologically oriented and functionally oriented sectors of exploratory development, such that the results of the work in the former may serve directly as inputs into the latter.

OBJECTIVES

The objective of the Navy's Exploratory Development program is to contribute to the solution of specific military problems and to respond to fleet and field operational needs. The Chief of Naval Operations and the Commandant of the Marine Corps establish requirements which express the desires for an operational capability to carry out planned missions and which state criteria which will be used in evaluating the producer's response and which include consideration of the strategies, tactics, and economies involved. Goals for Technology in Exploratory Development (FDG's) are quantitative Goals for Exploratory Development which, if met, would provide the technical means to satisfy operational requirements for future weapons and support systems. They are based on the General Operational Requirements, Long-Range and Mid-Range planning documents, and a predicted threat. These quantitative goals do not [illegible] ational [illegible] the time frame covered by the technological forecast.

A meaningful technological forecast would assist in providing inputs in:

a. Making a technically sound postulation of the enemy threat in the forecast period which produces the base necessary to evolve general requirements (complete interpretation, understanding, and dissemination of the threat is beyond the responsibility of the forecast).

b. Defining general requirements to meet and/or exceed the projected threat of the forecast period.

c. Establishing U.S. technological capabilities projected to the forecast period and specifying in general the time-phasing and steps of progression to reach defined milestones.

d. Identifying the vital technological parameters and performance levels in each component or concept area; determining the level of technology that will be required in these parameters for each projected operational capability, and the confidence with which it is expected that these levels, will be reached with programmed funding and at accelerated funding levels; identifying any parameters in which there are serious gaps between the required and programmed levels of capability.

e. Outlining a matrix for technology/capability which can be refined and used as a base for defining possible systems after general requirements for the enemy threat are defined.

f. Examining the extent of interdependence of the various technical disciplines and assessing the manner in which advances in one technical area will affect the advances needed by and capable of achievement in one or more related technical areas.

g. Identifying critical technologies, including promising technology of intuitively high payoffs not directly responsive to the threat, and resource levels required to support these technologies.

h. Identifying advanced technologies which will enhance capability and effectiveness in fulfilling mission capabilities.

i. Defining the impact of limits and restrictions imposed by policy on technology.

PROCEDURE

Each preparer of a forecast should undertake an intensive review of his technical field, in terms of an outline of expected advances in each technical area with emphasis on areas of special technical promise in the forecast period. Wherever possible, achievable technical goals over the period should be identified by parametric performance limits. The projection should be made with and without consideration of known and forecastable constraints. Progress assuming "level" and accelerated funding to achieve these goals should be included. A successful forecasting effort requires creative analysis of thoughtfully projected and technically feasible goals. The analysis can be integrated into mission- and system-oriented capabilities. This analysis must be based on an understanding of U.S. policy and military considerations and advances in technology. Each forecast, on one hand, should be responsive to the threat and the other promising technology which could transcend and precede future enemy threats and, on the other hand, should identify technical support facilities to support the promising technology program.

Section 2. CATEGORIES

Appendix B presents a grouping of the individual technological forecasts which would make up Part II of the Navy Technological Forecast. The categorization would serve as a Table of contents if the forecasts were assembled in one document and would serve as a means of dividing the material if a series of reports were published similar to Technical Objectives Documents, prepared by the Research and Technology Division, Air Force Systems Command.

Appendix B groups the individual elements according to technology or function in a manner very similar to that used in the NAVMAT Informal Study, "Exploratory Development Requirements (Elements)." The listing includes cross-referencing to the Exploratory Development Requirements and Exploratory Development Elements, wherever available.

The technological elements listed under Section 1 of Appendix B are directed to making available the technical knowledge required to effectively develop future components or systems to satisfy naval needs. Generally, the work will not be directly associated with its application, but rather, will be directed toward the advancement of the technological state-of-the-art. The functional elements, on the other hand, are directed to the development or improvement of a component or subsystem for operational use. In this area, the feasibility of the end objective is not evident at the onset of the work and the specific application necessitates a multidisciplinary use of knowledge from more than one technological element. Descriptions of several exploratory development elements are given in Appendix A.

Section 3. FORMAT

Each technological capabilities forecast will be organized according to a standard format for purposes of establishing a uniform method of presentation. Each preparer will, of necessity, exercise freedom in his presentation of the contents of his forecast because of the large variations in approach from one technological area to another.

CONTENTS OF FORECAST

Each technological capabilities forecast shall include, when applicable, one or more of the following elements:

a. Background
b. Present Status
c. Forecast of Future State-of-the-Art
d. Operational Implications
e. Associated R&D Organizations
f. References

Elements (a), (b), and (c) make up the essential parts of the forecast; element (d) constitutes the scientist's or technologist's appraisal of the Exploratory Development area in terms of meeting foreseeable naval requirements and objectives. Elements (e) and (f) are intended to give the reader reference material for more detailed study of the area covered by the forecast.

BACKGROUND

This Section outlines the results of recent, current, and anticipated applied research in the specific Exploratory Development area in terms of its relevance to meeting future naval requirements. The objective of the research is defined and the relationship of the work in this area to that in other Exploratory Development areas, on which its success depends at least in part or to whose success it contributes, is delineated.

PRESENT STATUS

The current state-of-the-art in applied research is briefly described, with emphasis on pertinent problem areas in terms of relevance to stated and anticipated Naval requirements. In some instances, the state-of-the-art may be summarized in a quantitative analysis of the trends of one or more parameters which are critical to the research and development under consideration. Such analyses may be incorporated into the projection which is essential to the forecast.

FORECAST OF FUTURE STATE-OF-THE-ART

A technical forecast describes knowledge, capabilities, and equipments which science and technology can be expected to produce over the specified time frame, if supported by orderly programs of research and development. Since the forecast is not a plan, it is not to be identified as a commitment to a given development or material.

Wherever possible, each technological forecast will be a quantitative projection of a parameter which is critical to the research and development under consideration. Several parameters will be involved in the forecast, but normally, only one is functionally independent. It is desired that the forecast include a projection of the growth trend of this parameter during the forecast period, descriptions of the interrelationships of other significant characteristics with the critical parameter, and the influence of constraints (e.g., weight, space limitations, need for cryogenic cooling, etc.).

Examples of how to present parameter trends are included in Section 4, Chapter 3.

Whenever the forecast involves alternative approaches, the advantages and disadvantages of each should be spelled out in quantitative terms.

When it is calculable, the influence of naval level of support on anticipated progress should be specified explicitly, as well as an expression of the level of confidence which is applicable to the forecast.

Tabular presentations of relevant data, when employed, should be concise.

OPERATIONAL IMPLICATIONS

Operational capabilities and changes in operational tactics which are achievable together with forecasted developments in the area under consideration are identified. Requirements on technology stemming from gaps in the technical support of the operational state-of-the-art are also identified.

Potential high pay-off areas in terms of foreseeable naval missions are identified for which financial support will lead to greater potential gain or to an earlier improved operational capability.

Low pay-off areas are called out and assessed in terms of:

a. High risk versus limited potential gain

b. Remote relevance to anticipated naval requirements

c. Diminishing returns in view of approaching state-of-the-art limits and other predictable dead-ends.

ASSOCIATED R&D ORGANIZATIONS

Pertinent naval R&D organizations associated with specific Exploratory Development area should be listed.

REFERENCES

All documentation relevant to subject at hand should be included.

E. ASSOCIATED R&D ORGANIZATIONS

U.S. Navy Mine Defense Laboratory, Panama City, Florida.

F. REFERENCES

None.

SAMPLE FORECAST

TECHNOLOGICAL CAPABILITIES

Section 1.1 - MATERIALS TECHNOLOGY*
1.1.1 Metallic Materials*

Aluminum

A. BACKGROUND

High-performance aerospace vehicles have placed quite severe design requirements (strength-weight ratio, ductility, temperature resistance, etc.) on the materials used in their construction. One material which has been capable of meeting most of these requirements is aluminum and its alloys.

B. PRESENT STATUS

The wrought Al-Mg-Zn alloys exhibit the highest strengths available in aluminum alloys at room temperature. Research efforts on these alloys have been concentrated on improving strength retention at elevated temperatures, ability to be heat treated in heavy sections, corrosion and stress corrosion resistance, and weldability.

C. FORECAST

The long-range outlook for improvement in aluminum alloys is not particularly encouraging. Some gains will be made in improving stress and intergranular corrosion resistance with moderate improvements in strength, heat resistance, and welding characteristics (Fig. 5.4). There is little likelihood that short-term heat resistance beyond 700 F will be achieved. The use of large castings will decline owing to the relative high cost of manufacture compared to the fabrication of large welded parts.

D. OPERATIONAL IMPLICATIONS

Aluminum will continue to be the basic material for subsonic aircraft construction and for the interior structure of transonic and supersonic vehicles. Some further usage in underwater ordnance and submarine vehicles can be anticipated.

*Numeric designations are defined in Appendix B.

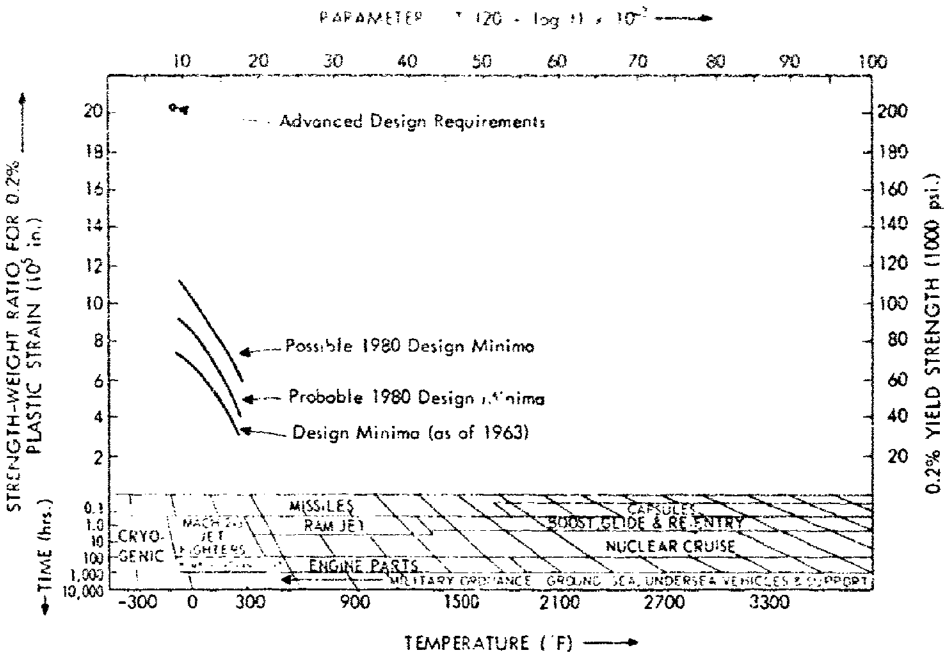


Figure 5.4. Light Metals-Low Melting Point (Aluminum)

E. ASSOCIATED R&D ORGANIZATIONS

NRL, Washington, D. C.
NASL, Brooklyn, New York
DTMB, Carderock, Maryland
MEL, Annapolis, Maryland
NAEC, Philadelphia, Pennsylvania
NOL (WO), Silver Spring, Maryland

F. REFERENCES

"Long Range Forecast for Materials," Draft Report of Navy Advisory Council on Materials (NACM) Sub-Committee on Materials Classification, October 1964.

"Status and Projections of Developments in Hull Structural Materials for Deep Ocean Vehicles and Fixed Bottom Installations," Edited by W. S. Pellini (Back up Report, Undersea Technology Panel, Project SEABED), NRL Report 6167, November 1964.

Magnesium

A. BACKGROUND

Large increases in missile and aircraft capabilities would be realized if the structural materials could be reduced in weight. Research in magnesium and its alloys is being pursued to meet this goal of improved and lower weight structural materials.

B. PRESENT STATUS

The design stress values for magnesium alloys at room temperature are low, limiting use of the material to situations in which strength weight ratio is the major consideration and stiffness is not a factor. Performance at low temperatures is not outstanding. At elevated temperatures, reasonably good properties at 600 -700 F are exhibited by the Mg-Th-Zr alloys which have excellent weldability.

C. FORECAST

It is anticipated that by 1985 the properties of Mg-Th-Zr alloys at 600 -700 F will have been improved substantially. Because of their low density and high heat conductivity there probably will be a gradually increasing use of these materials for moderately stressed aircraft and missile structures. While there will be some improvements in the properties of protective coatings, susceptibility to corrosion will continue to be a principal deterrent to wider structural use of magnesium alloys in military equipment.

D. OPERATIONAL IMPLICATIONS

Magnesium and its alloys will continue to find use in operational equipment because it is light weight. However, its susceptibility to corrosion will make its use limited.

E. ASSOCIATED R&D ORGANIZATIONS

NAEC, Philadelphia, Pennsylvania
NASL, Brooklyn, New York
NRL, Washington, D. C.

F. REFERENCES

"Long Range Forecast for Materials," Draft Report of Navy Advisory Council on Materials Sub-Committee on Materials Classification, October 1964.

"Status and Projections of Developments in Hull Structural Materials for Deep Ocean Vehicles and Fixed Bottom Installations," Edited by W. S. Pellini (Back-up Report, Undersea Technology Panel, Project SEABED), NRL Report 6167, November 1964.

Beryllium

A. BACKGROUND

A major factor in the evolution of today's highly efficient jet engines, aircraft, and missiles has been the development of a series of high-temperature-resistant, high-strength alloys with good fabrication properties. Similar but gradual advances during the next 20 years will be marked by longer life stress—high-temperature conditions, coupled with the development of new manufacturing processes will help insure the development of even more efficient engines, aircraft, and missiles. In the cool end of the jet engines, for example, the low-density beryllium alloys offer the greatest promise for achieving improvements in operating efficiency.

B. PRESENT STATUS

Beryllium appears highly attractive for structural applications because of its very low density (1/4 that of steel, 2/5 that of titanium), high modulus of elasticity (50% higher than steel, 300% higher than titanium), good thermal conductivity, and high melting point. On a modulus/density basis, no metal approaches the potential of beryllium. Principal deterrents to its use are the inherent brittleness of the materials, its toxicity, and its very high cost. The Navy is concentrating a major research study on the brittleness problem. It is expected that costs will decline as new alloys are developed and put to use and that the material will become competitive for a number of applications.

C. FORECAST

The long-range outlook for the improvement of beryllium is optimistic (Fig. 5.5). Although still in its infancy, the development of beryllium as a truly useful engineering material with high strength and usable ductility is well on its way as a result of recent and current research. Further improvement appears certain, which will include at least the development of a material with uniformly reliable mechanical properties at a relatively low tensile strength level. A material with twice the strength of present-day commercial grade beryllium (e.g., 160,000 psi compared to 80,000 psi) and improved ductility appears feasible. Such a material would be superior on a strength/density basis to all fabricable structural materials at temperatures to 800 F.

D. OPERATIONAL IMPLICATIONS

Beryllium has promise as an improved material for potential application in jet engine compressor blades, stator vanes, compressor discs, and other jet engine parts, airframe structures, and space vehicles. Consideration of beryllium will be particularly favored for applications in which stiffness is a primary load determining factor.

E. ASSOCIATED R&D ORGANIZATIONS

NAEC, Philadelphia, Pennsylvania

F. REFERENCES

"Long Range Forecast for Materials," Draft Report of NACM Sub-Committee on Materials Classification, October 1964.

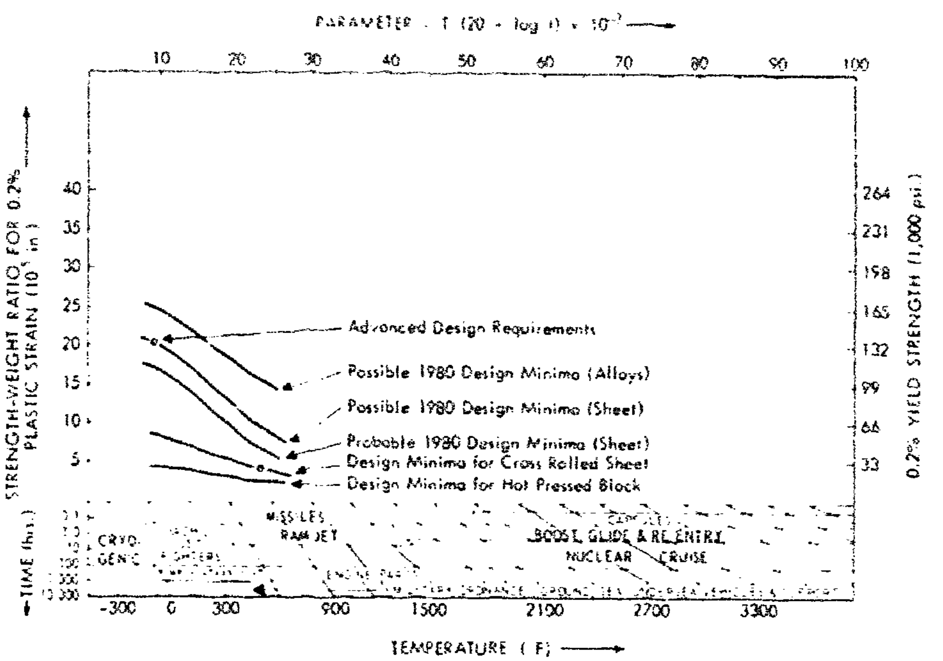


Figure 5.5. Light Metals-Stiff (Beryllium)

"Status and Projections of Developments in Hull Structural Materials for Deep Ocean Vehicles and Fixed Bottom Installations," Edited by W. S. Pellini (Back-up Report, Undersea Technology Panel, Project SEABED), NRL Report 6167, November 1964.

Titanium

A. BACKGROUND

Titanium alloys are attractive materials for use in both the air and sea environment. For the air environment, they are attractive because of their high melting temperature and excellent strength-to-weight ratio over a range of temperatures from about -80 F to upward of 1000 F. For the sea environment and particularly for submarine hulls, they are attractive due to the above properties and also because they are non-magnetic, corrosion resistant, and have a high modules.

B. PRESENT STATUS

Recent advances have been concerned principally with establishing production and fabrication techniques for alloys developed in the mid- and late-1950's.

C. FORECAST

The potential of titanium remains only partially explored. Between 1965 and 1985, emphasis will be on the development of new alloys to meet advanced design requirements for aircraft and missiles, as shown in Fig. 5.6. It is anticipated that some of these alloys will be suitable for short-term use in the 1200 - 1800°F range.

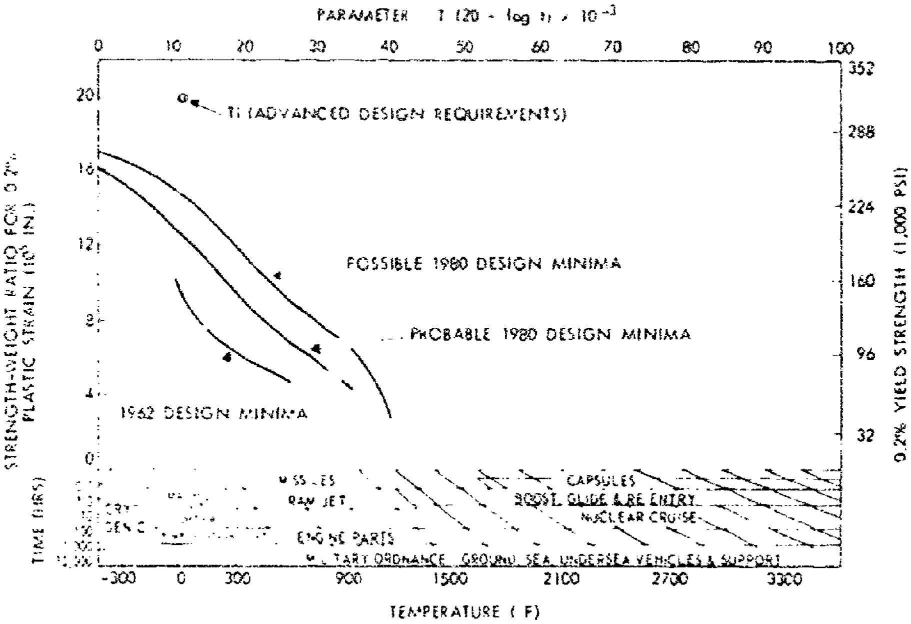


Figure 5.6. Light Metals (Titanium)

Figure 5.7 presents estimated probable gains that will be made up to 1980 in mechanical properties for titanium alloy sheet and plate. Estimates of the growth that can be expected to take place in the titanium metals industry by 1980, including cost trends, are shown in Fig. 5.8.

Figure 5.10, in the section on steel, shows the gains to be expected in various materials by 1970 for use in submarine hulls. The solid black line at the 1.0M ratio establishes a long-term somewhat optimistic limit, based on the use of Ti-160, for the fabrication of large underwater structures with a high degree of fracture safety. This is considered the ultimate projection for designs based on established structural concepts for ductile materials.

D. OPERATIONAL IMPLICATIONS

Operational capabilities will be greatly improved as titanium alloys are discovered and the fabrication problems are resolved. Such improvements will be seen in higher performance aircraft due to the increased usable temperature range and improved operating efficiency for jet engines. Deeper operating submarines will become possible but these will increase the ASW problem by enlarging the search volume.

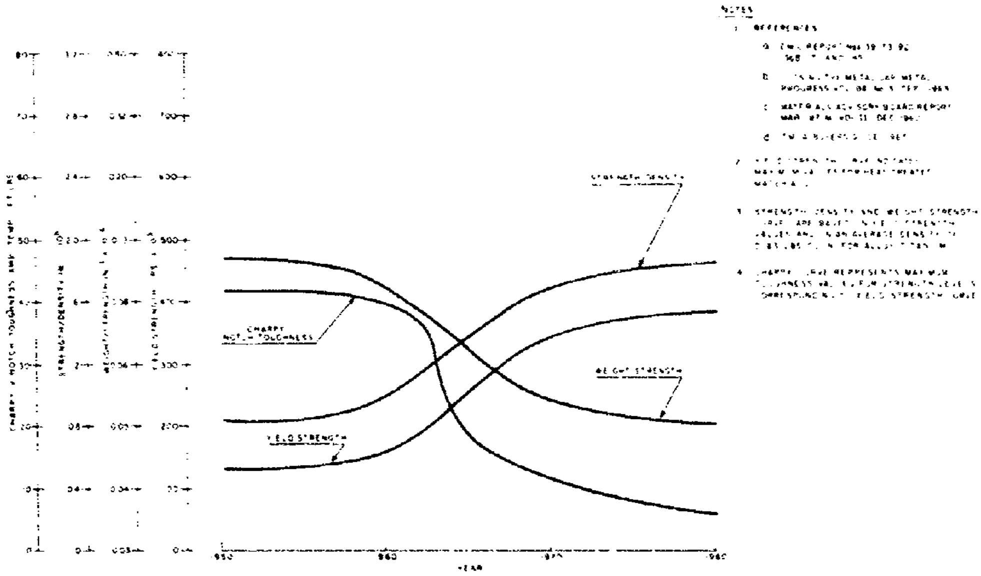


Figure 5.7. Mechanical Properties, Titanium Alloys

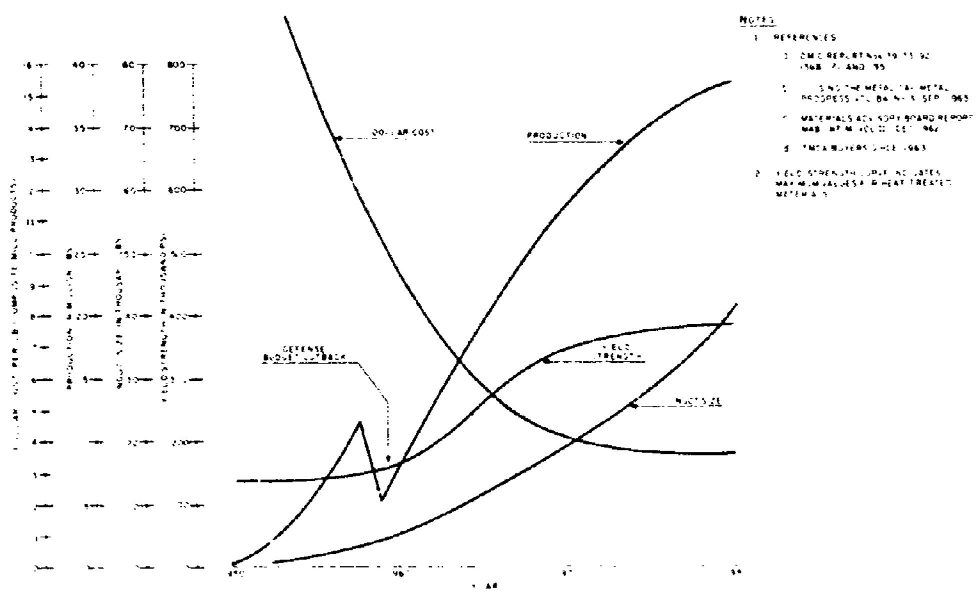


Figure 5.8. Titanium Metal Development

E. ASSOCIATED R&D ORGANIZATIONS

NRL, Washington, D. C.
DTMB, Carderock, Maryland
MEL, Annapolis, Maryland
NASL, Brooklyn, New York
NCEL, Port Hueneme, California
NAEC, Philadelphia, Pennsylvania
NOL (WO), Silver Spring, Maryland

F. REFERENCES

"Long Range Forecast for Materials," Draft Report of NACM Sub-Committee on Materials Classification, October 1964.

"Status and Projections of Developments in Hull Structural Materials for Deep Ocean Vehicles and Fixed Bottom Installations," Edited by W. S. Pellini (Back-up Report, Undersea Technology Panel, Project SEABED), NRL Report 6167, November 1964.

Steel

A. BACKGROUND

Steel in one form or another has been the primary material used by the military. Quenched and tempered steels have been produced in large tonnage quantities for military applications as plate and forgings; these have included WW2 armor plate ranging from 3 to 16 inches in thickness and submarine hull steels (HY-80) of 2 to 3 inches in thickness. In addition, a wide variety of industrial plate (of lower alloy contents than HY-80) has been produced since the middle 50's for welded fabrication at strength levels of 100 to 115 thousand psi. High-strength forgings (such as aircraft landing gears) have been produced in large quantities in the past 20 years at strength levels in the 180 and 230 thousand psi range and more recently in the 230 to 260 thousand psi range.

B. PRESENT STATUS

Ultra-high-strength wrought structural steels are one of the most widely used systems of alloys and are extensively used in the range to 1200 F. These and the more corrosion and oxidation resistant "stainless" steels offer excellent promise for major strength-to-density gains between now and 1985. For example, in the ultra-high-strength field, experimental steels have been produced by ausforming and strain aging which develop yield strengths of 500,000 psi with measurable ductilities.

C. FORECAST

By 1980 it is expected that heat-treated steels with at least 335,000 psi yield strength will be available on a production basis. Beyond this, specialists foresee the development of steels which will attain yield strengths of 430,000 psi at 600 F and 325,000 psi at 1000°F. Estimates of the advanced design requirements and future trends in mechanical properties of ultra-high-strength steels are shown in Fig. 5.9.

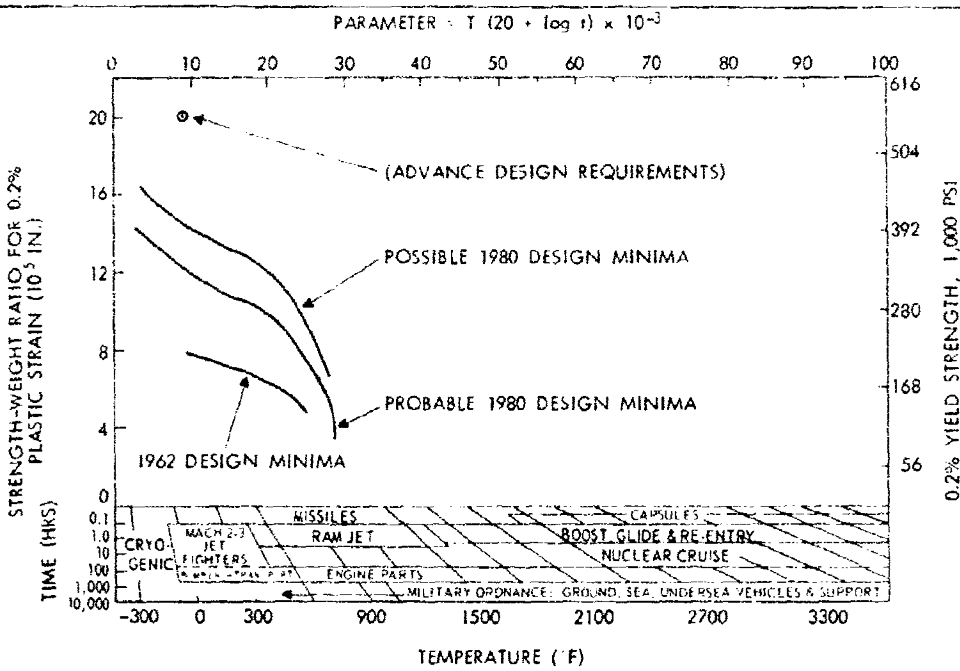


Figure 5.9. Low and Medium Alloy, Ultra-High-Strength Steels

Steel wire with a guaranteed strength level of 575,000 psi is now available commercially. The development of wire with strength levels approaching 1,000,000 psi appears likely by 1985.

The high-strength potential of steel will also be exploited in the development of ultra-fine wire or "whiskers." Here the problem will be to orient and combine these whiskers in sufficient number and in a manner which will enable the development of their known high strengths, or conversely, to design the sizes, constituents, and phases of the microstructure to whisker size. Substantial gains in achieving these goals are expected by 1980.

Notwithstanding prospective strength gains, the high density of stainless alloys will tend to confine heir use to applications in which stiffness as a load determinate is secondary.

The use of HY-150 steel is projected to about 1970 to meet current requirements for large hull structures. Thereafter, the predictions for other materials that might be used and the effective strengths that probably can be utilized are shown in Fig. 5.10 simply as an "envelope of research opportunity." The order in which the materials appear does not necessarily indicate their relative importance in the design of various vehicles, or the order in which they should or will be exploited, or the effort to be expended on each. The solid black line at the 1.0 yield strength to density ratio establishes a long term somewhat optimistic limit, based on the use of Ti-160, for the fabrication of large underwater structures with a high degree of fracture safety. This is considered the ultimate projection for designs based on established structural concepts for ductile materials. For shorter periods, designs will be based, of necessity, upon the use of more conventional HY-180 steel and Ti-120 materials, with yield strength density ratios of 0.6 and 0.8, respectively. The figure notes that below the dividing line the problems are primarily metallurgical, with welding a factor of major concern. Above this line, a new

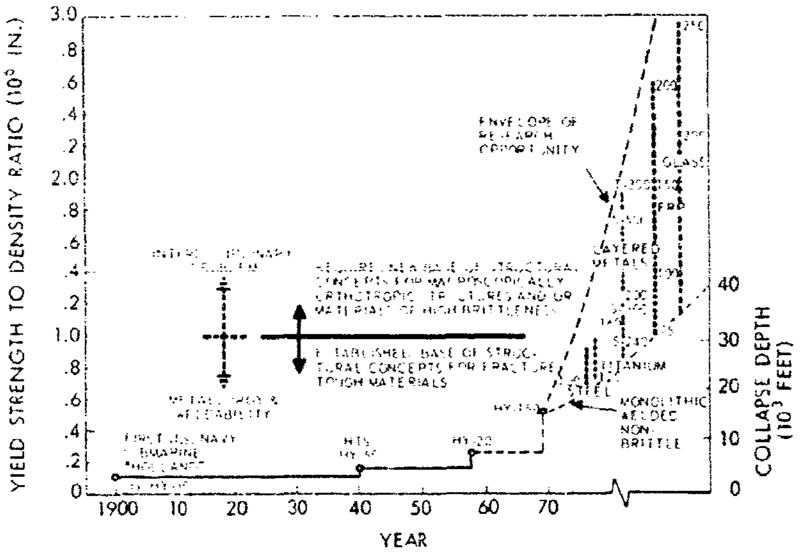


Figure 5.10. Evolutionary and Future Projections of Relative Structural Efficiency of Submarine Hull Structures

base of structural design concepts must be evolved if the orthotropic and non-ductile materials are to be used successfully.

It is not likely within the next ten years that there will be sufficient time to develop adequate fabrication and design techniques for fracture-sensitive materials for large underwater vehicles.

D. OPERATIONAL IMPLICATIONS

The improvements discussed in the preceding section will provide the Navy with new steels for use in various hardware applications. Such applications would include deeper diving combatant submarines, small research submarines, and rescue submarines. These latter could make possible the use of the ocean floor for such purposes as commercial mining, bottom sonar stations, and bottom missile sites.

E. ASSOCIATED R&D ORGANIZATIONS

NRL, Washington, D. C.
NOL (WO), Silver Spring, Maryland
NAEC, Philadelphia, Pennsylvania
NASL, Brooklyn, New York
MEL, Annapolis, Maryland
NCEL, Port Hueneme, California

F. REFERENCES

"Long Range Forecast for Materials," Draft Report of NACM Sub-Committee on Materials Classification, October 1964.

SAMPLE FORECAST

"Status and Projections of Developments in Hull Structural Materials for Deep Ocean Vehicles and Fixed Bottom Installations," Edited by W. S. Pellini (Back-up Report Undersea Technology Panel, Project SEABED), NRL Report 6167, November 1964.

CHAPTER 6

PART III — PROBABLE SYSTEMS OPTIONS

Section 1. INTRODUCTION

The Technological Capabilities Forecast provides a compendium of anticipated advances and capabilities in technology which can be used as "building blocks" in conceiving systems which would enhance the performance of the fleet. These system concepts or suggested technically feasible solutions to projected naval needs provide a valuable "look into the future" for the planner of potential systems as well as to management personnel who must support the associated development programs.

Current policy as promulgated by Department of Defense Directive 3200.9, under the title, "Project Definition Phase" (PDP), requires that certain requirements must be met before the development of a system is initiated. It is applicable to that phase of development in which major commitments of research and development or production money are made with serious consequences obtaining if subsequent changes or cancellations are made. The policies expounded were designed to assure readiness for engineering development by exhibition of achievable performance specifications, the accomplishment of which would be done under Pre-PDP. In July 1965, the Directive was re-issued under the name of "Contract Definition" requiring a preliminary phase of "Concept Formulation."

As defined in DOD Directive 3200.9, Concept Formulation describes the activities preceding a decision to carry out Engineering Development. These activities include accomplishment of comprehensive system studies and experimental hardware efforts under Exploratory and Advanced Development, and are prerequisite to a decision to carry out Engineering Development.

Four fundamental steps associated with the decision-making process are applicable to Concept Formulation, namely: establishing the objective or overall results which are sought, identifying the alternative ways of achieving the objective, comparing these alternatives to established criteria, and selecting the most suitable alternative.

Our nation's dynamic technology offers the fleet the prospect of new capabilities and opportunities to impose new threats on potential enemies. It is the purpose of Probable Systems Options (Part III of the Navy Technological Forecast) to present such opportunities in terms of functions to be performed and overall capabilities which can be achieved. They would find their place in the statement of Contract Formulation Objectives for major system developments. Part III would present candidate equipments for consideration in meeting current deficiencies, in providing replacements for obsolescent systems and equipments, in identifying threats likely to be imposed by potential enemies, and in outlining system parameters to counter such threats.

The Navy's Exploratory Development program is largely devoted to creating new technological opportunities. In Part III, the forecaster shares the responsibility to insure timely exploitation of these opportunities. Part III assists the decision-maker by identifying and describing alternative approaches to meet a functional need. In the Concept Formulation process these approaches may be compared from both a technical and cost effectiveness point of view, on a level of examination necessary to establish an Advanced Development project, or to support a conditional approval for a major Engineering Development project.

It is emphasized that one cannot forecast the availability of a conceptual system prior to a decision to support its development. One can, however, forecast the capability to develop the system. Such capability can be predicted on the basis of the feasibility of technological advances forecasted under Technological Capabilities (Part II).

The scope of the material forecasted in Part III should be constrained to concepts which have naval relevance and are supported by preliminary feasibility studies. These studies would be parametric analyses of the several subsystems and components involved in the system concept. A cost effectiveness analysis would not necessarily be made. The report describing the proposed system and its technical and operational characteristics would be summarized for inclusion in Part III of the Navy Technological Forecast.

Section 2. CATEGORIES

Table 6.1 presents the proposed listing of categories under which the individual forecasts of Probable Systems Options (Part III) of the Navy Technological Forecast would be grouped. The categorization would serve as an index to the volume of looseleaf entries which would have to be updated at periodic intervals. Each forecast would be identified according to warfare area and/or functional area as appropriate.

Table 6.1
Proposed Systems Categories

Warfare Areas
Strategic Warfare — Air, Surface, Undersea
Tactical (Strike) Warfare — Air, Surface, Undersea
Amphibious Warfare — Air, Surface
Anti-Submarine Warfare — Air, Surface, Undersea
Fleet Defense — Air, Surface, Undersea
Space Applications
Functional Areas
Vehicle — Aircraft, Ships, Undersea Craft
Weaponry — Conventional Munitions, Guns, Torpedoes, Missiles, Mines, Special
Surveillance and Navigation — Radar, Navigational Equipment, Sonar Cameras, IR Sensors
Communications, Command and Control — Communication Equipment, Displays, Data Links, Fire Control
Countermeasures — ECM, Minesweeping, Decoys, Degaussing
Personnel Support — Messing, Clothing, Medical Aspects, Training
Logistics — Packaging, Handling, Transport
Target Environment — Air, Surface, Undersea, Shore

To avoid unnecessary duplication, greater emphasis will be placed on major subsystem and or systems in Part III, whereas foreseeable minor subsystems and/or components may properly be included in Part II.

Section 3. FORMAT

Each forecast will be organized according to a standard format for purposes of establishing a uniform method of presentation. The preparer will, of necessity, have to exercise freedom in his presentation of the contents of his forecast because of the large variations in approach from one technical area to another. It is suggested that the following elements be included, when applicable, for each entry.

A. New Capabilities

1. How technology is evolving to provide the new capabilities.

2. Limitations of existing systems versus proposed capabilities.

3. Forecast of technological parameters upon which feasibility is based.

B. Technical Approach

1. Functional diagram.

2. Description of the functions, components, and technology.

C. Operational Effectiveness

1. Operational diagram.

2. Proposed doctrine for Navy utilization.

3. Alternate operational uses.

4. Quantitative functional capabilities.

D. Critical Technology

1. List of technological gaps.

2. Degree and criticality of gaps.

E. References

Section 4. SAMPLE FORECAST

A sample forecast has been prepared, only to demonstrate the format outlined above. The example is based on documentation (BUWEPS, RM 67-1A June 1965, Project SMEADO '67) available to the Navy Technological Forecasting Study Group, but only for the purpose of demonstrating format. It is to be noted that the example was prepared in 1961, it would represent a forecast at that time, even though it is essentially state-of-the-art in terms of today's (1966) technology.

CHAPTER 7

TECHNOLOGY NEEDS IDENTIFICATION STUDIES

Section 1. INTRODUCTION

To continue its role in maintaining the freedom of the seas, the Navy is constantly looking to technology for improvements in its capability. A research and development program is maintained to further technological advance to assure this increased capability. Managers and operational planners are anxious to know what can be expected from the research and development presently underway or anticipated. The Navy Technological Forecast is expected to provide them with much of the desired information.

The basic forecast discussed in the previous chapters will show the expected improvements in the Navy science (Scientific Opportunities) and technology (Technological Capabilities) areas and the results of preliminary system analyses (Probable Systems Options). The Technology Needs Identification Studies are to be used when a comprehensive investigation of a particular technological area or mission area is desired.

The Technology Needs Identification Study (TENIS) approach as visualized in this report is in reality a planning procedure. However, its results are very dependent on a good, detailed technological forecast and in some cases the study results themselves may be considered a forecast.

Technology Needs Identification Studies will vary in size depending on the type of study being conducted. Most studies will probably be small and can utilize the method of operation of the technical workshops. However, studies the size of Project SEABED or Project FORECAST may be necessary.

A Technology Needs Identification Study addresses itself to the following five tasks:

1. Select the problem or objective

2. Conduct the forecast of technology

3. Determine the system or program alternatives

4. Analyze the alternatives

5. Select the system(s) and/or define the R&D program

These tasks are very similar to the steps followed during the concept formulation phase of the R&D cycle; therefore, these studies could find great utility in concept formulation.

Of the tasks stated above, the conduct of the forecast is by far the most important since all study results are based upon it. The forecasts made in these studies are restricted to those necessary to provide a solution to the problem under investigation. They are prepared prior to the study as shown in Fig. 7.1 and are in much greater detail than the forecasts for the Scientific Opportunities and Technological Capabilities Parts of the Navy Technological Forecast. System alternatives for the Probable Systems Options Part will also be prepared if the study requires a system(s) solution. The forecasts will be prepared using methodologies similar to those described in Chapter 3 and in a format compatible with the basic forecast. The forecasts will use any forecasts which are available and should be in a form easily used by a system designer or technology reference source.

CHAPTER 8

IMPLEMENTATION

Section 1. RESPONSIBILITIES

PRIMARY RESPONSIBILITY

Navy R&D laboratories, with assistance from academic organizations and industrial concerns via the laboratories' normal associations, should be assigned primary responsibility for gathering the technical data and information needed to prepare the individual forecast items for the overall NTF. The flow of information is shown in Fig. 8.1.

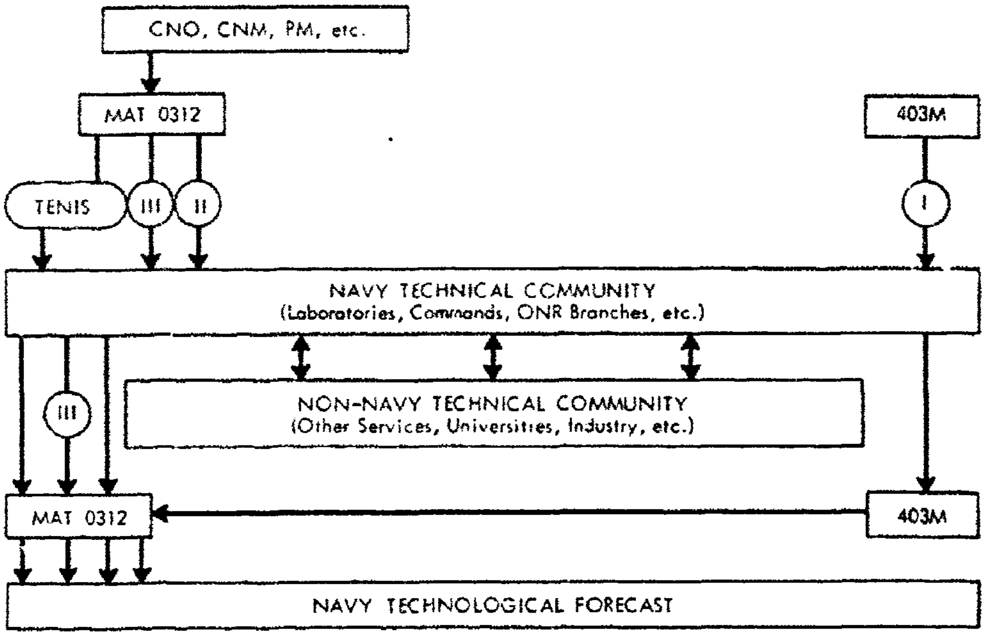


Figure 8.1. Navy Technological Forecast Management Responsibilities

SUPPORTING RESPONSIBILITY

Representatives of the Chief of Naval Research and the Chief of Naval Development, as shown in Fig. 8.2, should share the supporting responsibility for assigning areas of Navy technology to be forecast, managing and providing guidelines, and preparing the overall NTF. The Chief of Naval Research should be responsible for Part I and the Chief of Naval Development for Parts II and III of the forecast.

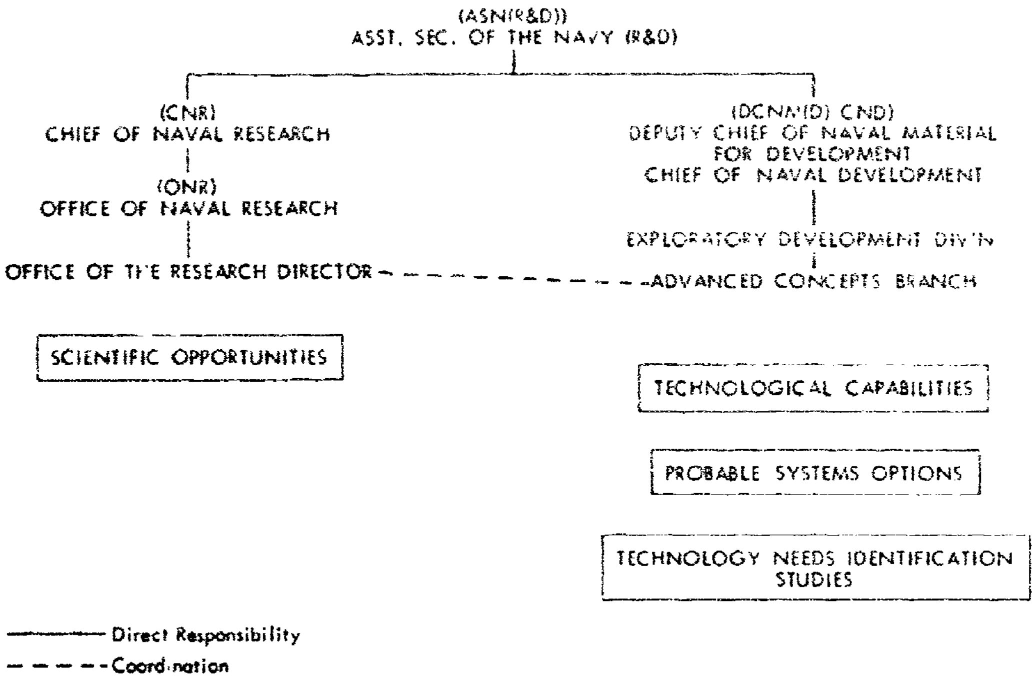


Figure 8.2. Headquarters, Technological Forecasting Responsibilities

COORDINATING RESPONSIBILITY

The Chief of Naval Development should assume the coordinating responsibility for the entire NTF as well as the final documentation of the integrated product. A small group should be designated the Technological Forecasting Group (TFG) and should have the responsibility for coordinating the total effort under the primary direction of the Chief of Naval Development.

The responsibilities of the primary, supporting, and coordinating activities should be as follows:

The responsibilities of the Technological Forecasting Group (TFG) should be:

1. To recommend areas of R&D to be forecast by the Office of Naval Research, Naval Systems Commands, Offices, Bureaus, and Laboratories.

2. To coordinate all efforts with ONR, Systems Commands, Offices, Bureaus, and Laboratories in order to generate the NTF.

3. To coordinate the NTF with the Marine Corps.

4. To collect, review, publish, distribute, and update the NTF.

5. To contact the Army and Air Force forecast groups, as necessary.

The responsibilities of the Chief of Naval Research, within his area, should be:

1. To update the forecast categories.

2. To delegate responsibility for forecasting to appropriate personnel.

3. To select significant areas to be included in the forecast.

4. To review and coordinate forecast materials.

5. To coordinate Part I with the TFG.

The responsibilities of the Chief of Naval Development, within his area, should be:

1. To review and identify significant categories to be forecast.

2. To delegate responsibility for forecasting to appropriate organizations.

3. To review and coordinate forecast materials.

4. To coordinate Parts II and III with the TFG.

The responsibilities of the Systems Commands, Bureaus, Offices, and Laboratories should be:

1. To identify significant categories to be forecast after coordination with the TFG.

2. To prepare forecasts.

3. To coordinate with other Navy organizations, other services, industry, and academic communities for assistance in preparing forecasts.

4. To update the forecasts after coordination with the TFG.

Section 2. IMPLEMENTATION REQUIREMENTS

SUGGESTION OF CATEGORIES TO BE FORECAST

Since it may not be possible for the initial forecast to cover all areas of Navy science and technology, it is proposed to limit inputs to the first Navy Technological Forecast effort to those areas of basic and applied science (Part I) which show great promise and to those areas of exploratory development which would have greatest potential technological utility. In Part III, laboratories and command technical offices submit Probable Systems Options which show the most promise.

ASSIGNMENT OF FORECAST CATEGORIES

Responsibility for the preparation of individual forecasts will be assigned to the various Navy-oriented laboratories based in part on proposals of the laboratories concerned. Assignments will be based on areas of expertise. In preparing inputs, however, it is desirable that all laboratories contribute to any area in which they have competence whether or not they are assigned as the principal forecaster. For example, Part I should reflect the anticipated results of the Fundamental Research Programs and Part II should include not only effort in direct support of a specific functional Exploratory Development Element, but also, that in support of another functional element which may be appropriately identified with the element in question.

GENERATION OF FORECAST INPUTS

When carrying the major burden of generating inputs to the forecast, the various in-house laboratories should draw on the expertise of the other segments of the Navy's scientific and technical organizations, the research and development activities of the Military Services, Government agencies, Industry, and the Academic Community. Inputs to Part III of the NTF will be made by the laboratories and technical offices of the systems commands and will result normally from parametric analyses of system concepts which have been developed at these levels. The results of studies made in the Navy Technical Workshops are another important source of inputs to Part III.

There are many ways in which a forecast can be compiled. During its study, the Navy Technological Forecasting Study Group considered five methods. The relative advantages and disadvantages of each are shown in Appendix D.

In compiling the forecast, the most desirable attributes of each of these will be used; however, the assignment of responsibility for specific forecasts to principal laboratories was considered the most practicable.

COLLECTION, REVIEW, AND EDITING OF FORECAST INPUTS

It will be the primary responsibility of ONR to collect, review, and edit inputs to Part I of the forecast. NAVMAT will be responsible for the same functions in Parts II and III of the forecast and in the Technology Needs Identification Studies. It is expected that the forecast data as submitted would be ready for final editing and publication. The two forecast offices may find it desirable to draw on laboratory and/or contractor assistance for this work.

PUBLICATION OF NAVY TECHNOLOGICAL FORECAST

NAVMAT will be responsible for the publication and distribution of the NTF. Consideration should be given in Parts I and II to publish the appraisal section of each forecast separately and with limited distribution, in comparison with the remainder of the Forecast.

The value of the NTF will be minimal unless it is published as early as possible following its preparation. For this reason, and to facilitate up-dating, the forecast should be printed in looseleaf form or as a series of documents. The results of the Technology Needs Identification Studies would be published as soon as possible following their completion.

SCHEDULING OF FORECAST

The first formal attempts in preparing the forecast undoubtedly will not encompass all areas of naval science and technology. The schedule of when the various areas will be forecast will be determined by the TFG based on the coordination of laboratory proposals. Technology Needs Identification Studies will be scheduled by NAVMAT as required.

UPDATING OF FORECAST

The preparing activities (laboratories, technical offices) will be responsible for updating Part III as new systems concepts emerge. NAVMAT will publish and distribute addenda to the basic document as appropriate. The individual entries in Parts I and II probably should be updated at least every two or three years.

SPECIAL REPORTS

Among the functions of ONR and NAVMAT in technological forecasting is the preparation of special forecasts and other reports (e.g., executive summaries) which may be required by higher management. It would also be the function of ONR and NAVMAT to stimulate new approaches to forecasting and to promote advanced methodologies and to maintain liaison with the other military services, Government agencies, and the academic community.

CHAPTER 9

INTERSERVICE FORECASTING

During the term of its duty, the Navy Technological Forecasting Study Group has given consideration to the implications and possible advantages of interservice forecasting. To this end, discussions have been held with technical representatives of the Marine Corps, with representatives of the Army Research Office and Army Materiel Command who prepare the Army Long Range Technological Forecast, and with representatives of the Office of Aerospace Research and the Air Force Systems Command.

Among the advantages of an interservice forecast is the exchange of information generated among the technical communities and laboratories of the several services. An interservice forecast may lead to less duplication of technical effort among the services and a good composite forecast could result in better systems for all services. A credible technological forecast can be convincing evidence of good interservice planning and can provide the visibility required for program support at top funding-decision levels.

On the other hand, it would be difficult to make an interservice forecast representative of the total defense RDT&E program; areas of investigation significant to one service are often not equally significant to others. The logistic problems involved in publication of an interservice forecast would be considerable; difficulties are foreseen in editing a copy mutually acceptable to all groups and in accommodating to the longer time interval between the initiation and publication of the forecast. The proposed NTF includes technical appraisal in terms of explicit Navy needs and missions not necessarily of interest to the other services.

The representatives of the Army, Air Force, and Navy have agreed in principle that the categories in the science or research area, which would be based on the current breakdown of defense research sciences and on the research objectives of the preparing service, would be common in most instances. Many elements in the Technology or Exploratory Development area are common to all services and would provide opportunities for liaison.

The Navy Technological Forecasting Study Group has concluded that interservice cooperation in forecasting should receive further consideration as it will prove to be advantageous in areas of mutual interest. However, the group recommends that an interservice forecast not be established until the Navy has developed a Technological Forecast which will meet its specific requirements, but that inputs into the forecasts of all services should be coordinated through common review in areas of mutual concern and interest.

APPENDIX A

PROPOSED NAVAL RESEARCH CATEGORIES (PART I)

(A proposed composite of Defense Research Sciences and Naval Research Areas)

I. Physical Sciences — 61245012-10

A. R001 General Physics — 61245012-11
- 01. Instrumentation
- 02. Solid State Physics
- 03. Atomic and Molecular Physics
- 04. Radiation and Optics
- 05. Acoustics
- 06. Plasma and Ionic Physics
- 07. Theoretical Physics

B. R002 Nuclear Physics — 61245012-12
- 01. Cosmic Radiation
- 02. Elementary Particles
- 03. Nuclear Structures

C. R003 Chemistry — 61245012-13
- 01. Physical Chemistry
- 02. Organic Chemistry
- 03. Inorganic Chemistry
- 04. Analytical Chemistry
- 05. Solid State Chemistry

D. R004 Mathematical Sciences — 61245012-14
- 01. Theoretical Mathematics
- 02. Applied Analyses, Theoretical Mechanics and Mathematical Physics
- 03. Numerical Analyses
- 04. Mathematical Statistics and Probability
- 05. Theories and Techniques of Logistical Analyses and Decision-Making
- 06. Theories and Techniques of Information Processing
- 07. Information Processing Systems and Devices
- 08. Mathematical Topics Relevant to Specific Military Problems
- 09. Basic Methodology in Systems Research
- 10. Interdisciplinary Research

II. Engineering Sciences — 61245012-20

A. R005 Electronics — 61245012-21
- 01. Electromagnetic Wave Propagation and Radiation
- 02. Physical Properties of Solids. Liquids and Gases
- 03. Electromagnetic Materials and Components
- 04. Electronic Theory
- 05. Contractor Laboratories

B. R006 Materials 61245012-22
01. Organic Materials
02. Lubricants
03. Inorganic Materials
04. Metals and Alloys
05. Composite and Fibrous Materials
06. High Temperature and Special Materials
07. Surface Phenomena, Corrosion and Prevention
08. Radiation Resistant Materials

C. R007 Mechanics 61245012-23
01. Hydrodynamics
02. Aerodynamics
03. Structural Mechanics

D. R008 Energy Conversion 61245012-24
01. Fuels and Propellants
02. Single-Step Energy Transformation
03. Multi-Step Energy Transformation
04. Energy Utilization

III. Environmental Sciences 61245012-30

A. R009 Oceanography 61245012-31
01. Physical Oceanography
02. Chemical Oceanography
03. Marine Biology
04. Marine Geophysics and Geochemistry

B. R010 Terrestrial Sciences 61245012-32
01. Earth Physics
02. Geography
03. Arctic Research
04. Environmental Factors

C. R011 Atmospheric Sciences 61245012-33
01. Atmospheric Physics

D. R012 Space Science (Added to DRS Elements)
01. High Altitude Physics
02. Astronomy
03. Radio Astronomy

IV. Life Sciences 61245012-40

A. R013 Biological and Medical Sciences 61245012-41
01. Regulatory Mechanisms
02. Immunology and Hematology
03. Biological Response to Environment
04. Microbiology
05. Biochemistry
06. Hydrobiology
07. Biophysics
08. Epidemiology
09. Biological Orientation
10. Ecology
11. Neurology and Neuropsychiatry
12. Surgical Sciences
13. Medical Sciences
14. Radiology, Pathology and Laboratory Sciences
15. Pharmacology

B. R014 Behavioral and Social Sciences 61245012-42

01. Sensory Mechanisms
02. Neural and Perceptual Processes
03. Motor Mechanisms
04. Psychological Traits
05. Selection Methods and Performance Criteria
06. Learning and Training
07. Individual Effectiveness
08. Group Effectiveness
09. Engineering Psychology

DESCRIPTION OF NAVAL RESEARCH CATEGORIES

(A proposed composite of Defense Research Sciences and Naval Research Areas)

I. Physical Sciences 61245012-10

A. R001 General Physics 61245012-11

01. Instrumentation: The study of new methods of measuring physical effects, which effects, in turn, may lead to new instrumentation capable of being used in missile guidance, reactors, high altitude and satellite systems.

02. Solid State Physics: The study on the physical properties of solids and interpretation of these properties in terms of quantum theory, thereby providing stronger foundations for metallurgy, optics, electronics and other applied sciences

03. Atomic and Molecular Physics: The study of the structure and properties of both atoms and molecules. A variety of techniques, such as optical spectroscopy, molecular and ion beam experiments and electron scattering are used to determine the properties of atoms and molecules. At the same time the quantum theory of microscopic interactions and statistical theories are studied and applied for the purpose of extending knowledge of the laws governing the physical behavior of both atoms and molecules.

04. Radiation and Optics: The study of some of the fundamental properties of space and matter which are required for a better understanding of such things as solar phenomena, the mechanisms involved in radiation transfer, the properties of new optical devices, and the nature of the atmosphere, both terrestrial and extraterrestrial.

05. Acoustics: The investigation of the properties of material using acoustics techniques, and the study of acoustical radiation as associated with mechanical, electrical and hydrodynamic processes and the description of such radiation as a function of various boundary conditions.

06. Plasma and Ionic Physics: The study of the properties of matter in the ionic and plasma states to obtain a comprehensive understanding and technological control of plasmas and ions in both the microscopic and microscopic domains; study of electron transport between conduction bonds of metals and absorbed gas molecules and ions in electrode surface electrostatic fields.

07. Theoretical Physics: The study of the fundamental physical laws of nature and the theoretical application of these laws into areas for which little experimental data exist. These areas are to include, but are not limited to, astrophysics, physics of aerospace, general relativity, quantum and statistical mechanics, field theory.

B. R002 Nuclear Physics 61245012-12

01. Cosmic Radiation: The study of the nature, origin, intensity and effects (interactions) of this extraterrestrial radiation.

02. Elementary Particles: The study of the nature, structure, properties, creation, destruction, and interaction of these building blocks of nature.

03. Nuclear Structure: The study of the nature of nuclear forces, structure and properties of various nuclei, and the interaction of radiation and elementary particles with various nuclei.

C. R003 Chemistry 61245012-13

01. Physical Chemistry: Molecular structure and its relationship to the properties of matter; thermochemistry; electrochemistry; chemical kinetics, including fast reactions; surface and colloid chemistry; theoretical chemistry with emphasis on problems in chemical binding; radiation chemistry; chemistry involving free radicals and excited species; the liquid state; chemistry at high temperatures; theory of reversible ionization at electrodes.

02 Organic Chemistry: Reactions of compounds containing large proportions of elements not usually found in organic compounds such as boron and metals; quantitative chemistry of inductive, resonance and steric effects on rates; mechanism of participation of solvents; physical properties of organic compounds and use of new physical methods to determine structures and reaction mechanisms.

03. Inorganic Chemistry: Synthesis structure and properties of inorganic compounds; mechanism of inorganic reactions; novel bonds between atoms.

04. Analytical Chemistry: Instrumental methods, tracer and hot atom techniques, other analytical problems.

05. Solid State Chemistry: The chemistry and structure of solids including the relationship of surface chemical phenomena (e.g., catalytic activity) to the electronic and defect structure of solids; electrochemical behavior of solids; solid-solid equilibria and reactions; the reactions and chemical properties of solids under extreme conditions of temperature and pressure; nonstroichiometric compounds.

D. R004 Mathematical Sciences 61245012-14

01. Theoretical Mathematics: Covering all the areas of pure or abstract mathematics, where research serves to augment mathematical knowledge without specific reference to particular current or potential domains of application.

02. Applied Analyses, Theoretical Mechanics and Mathematical Physics: Primarily concerned with the properties of ordinary and partial differential equations and associated boundary value problems, particular emphasis being placed on nonlinear theories as a vitally important area far from adequately covered by past research work.

03. Numerical Analyses: Particularly with reference to methods appropriate to electronic computation.

04. Mathematical Statistics and Probability: Including theories and methods relevant to the study and understanding of processes involving chance events and particularly to the acquisition analysis and interpretation of information from observation or experiment in situations characterized by uncertainty.

05. Theories and Techniques of Logistical Analyses and Decision-Making: Including the mathematical theories of programming, games, utility, logistical econometrics, management science, organization, information flow and processing relevant to naval logistics; and the derivation and testing of methods applicable to the planning and control of logistical and closely related naval operations by means of scientific techniques, primarily mathematical, and numerical simulation with the aid of electronic data processing.

06. Theories and Techniques of Information Processing: Including information, communication, servo-mechanism and learning theories, computer logic and design, information retrieval, machine translation, and analysis directed toward the further mechanization of processes naturally performed by the human brain.

07. Information Processing Systems and Devices: The innovation and improvement of components, devices, and systems for the rapid automatic acquisition, processing and/or utilization of information, together with physical investigations peculiarly relevant thereto.

08. Mathematical Topics Relevant to Specific Military Problems: Whose selection for investigation is determined by the need for new mathematically based techniques applicable in particular situations of military importance and not necessarily with regard to recognition of their significance as mathematical research areas; including investigation of new and improved methodologies for collection, collation, analysis and other processing of intelligence information, as well as of the logic, design concepts and component properties fundamental to the eventual development of systems for automatic processing of intelligence data.

09. Basic Methodology in Systems Research: Investigations and studies designed to improve the techniques and methodology for analyzing complex naval systems, particularly in the area of establishing better means of relating systems requirements and performance to the capabilities which can be provided by technology; including investigations of new and improved techniques for system analysis, automatic program optimization, adaptive systems studies, control system studies, automatic design aids, network synthesis, automatic data processing, mathematical techniques for operations research, systems reliability studies, organizational theory and cost-effectiveness studies.

10. Interdisciplinary Research: Investigations, involving several scientific and/or engineering disciplines (physics, aerodynamics, mathematics, human factors, etc.), and involving unique interactions or combinations of these disciplines, for the purpose of obtaining new knowledge, concepts, techniques and/or understanding of new phenomena; special emphasis being placed on research showing greatest potential for early Naval application; identification of gaps in the Naval research program requiring early investigation.

II. Engineering Sciences 61245012-20

A. R005 Electronics 61245012-21

01. Electromagnetic Wave Propagation and Radiation: Generation, transmission, absorption, radiation, scattering, refraction, diffraction, reception, amplification and presentation, over the range from extremely-low-frequencies to the millimeter-wavelength portion of the spectrum.

02. Physical Properties of Solids, Liquids, and Gases: Relating to electrical characteristics as conductivity, mobility, Hall, Zeeman and Faraday effects, plasma characteristics, magnetohydrodynamic, dispersive, polarization and other electrical properties, under varying physical and environmental conditions.

03. Electronic Materials and Components: Including new tube methods for microwave energy generation at high power and wide-bandwidth, new techniques for assuring low-noise receptors, solid- and vapor-state amplifiers and generators, as masers, and other stable frequency standards, parametric amplifiers, undulators, lumped and extended parameter oscillators, and growing families of semiconductor and ferrite devices, circuits and techniques, and materials for these applications.

04. Electronic Theory: Statistical approaches to problems in electromagnetic theory, antenna theory, circuit theory, communication theory, servomechanisms, magnetic and dielectric amplifiers systems design and prototype evolvement.

05. Contractor Laboratories:

B. R006 Materials 61245012-22

01. Organic Materials: Synthesis and properties of organic compounds; correlation of properties with composition and structure; methods for converting the synthetics to useful materials.

02. Lubricants: Synthesis, physical and chemical properties of solid, liquid and a gaseous lubricants.

03. Inorganic Materials: Research relating to the structure, chemical and physical properties of ceramics and inorganic nonmetallic materials.

04. Metals and Alloys: Research covering all metals and alloys from a general standpoint including their physical properties in the solid and liquid states; their use as structural materials, and fabrication and processing techniques.[1]

05. Composite and Fibrous Materials: Research covering bodies fabricated from two or more distinctly different materials for instance sandwich structures and laminated materials; also research directly supporting the development of synthetic and natural fibrous materials such as wood, cordage, leather, textiles, nylon, dacron, orion, and other synthetic filamentary materials.[2]

06. High Temperature and Special Materials: Research covering the behavior of metals, alloys and nonmetallic inorganic solids for use at high temperatures and for special application such as magnetic devices, cryogenic application, radiation resistance, energy conversion, etc.

07. Surface Phenomena, Corrosion and Prevention: Research concerned with the chemical, physical and mechanical phenomena which occurs at the surface of metals and alloys and lead to corrosion, pitting, stress-corrosion cracking, biological and chemical deterioration, etc.

08. Radiation Resistant Materials: Research concerned with the effects of nuclear radiation on the properties of materials.

C. R007 Mechanics 61245012-23

01. Hydrodynamics: The investigation of fluid motions and of their interactions with other media; and studies of the dynamic behavior of other media in liquids.

02. Aerodynamics: The investigation of the dynamic properties of gases and of their interaction with other media; and studies of the dynamic behavior of other media in gases.

03. Structural Mechanics: Research into the properties of structures and structural components, and investigation of their static and dynamic response to their environments.

D. R008 Energy Conversion 61245012-24

01. Fuels and Propellants: Synthesis, characterization, thermochemistry and reactions of chemical compounds with emphasis on structural types leading to energetic systems and the thermodynamics and kinetics needed to understand propellant performance, including sensitivity, ignition, combustion, transition to detonation, and equalibration in nozzle flow.

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[1] Research on ferrites, ferromagnetic materials and cements should be included under 04 or 05 unless such effort is more appropriate under R005-03 Electronic Materials and Components.

[2] In general, studies of individual components of composite or fibrous materials which are done for the distinct purpose of improving the material as such should be included under requirement 05. Studies of individual materials from a general standpoint should be included under the appropriate requirement such as 01, 03, etc.

02. Single-Step Energy Transformation: All the possible processes of transforming the primary sources of energy, such as chemical, radiant and nuclear to a more desirable form in a single-step are of interest, as for example, fuel cells, thermoelectric generators, solar cells and similar devices.

03. Multi-Step Energy Transformation: For various reasons, the desired transformation cannot always be effected satisfactorily in a single step but requires two or more as in chemically fueled, vapor or turbine cycles, nuclear powered vapor or gas turbine cycles, rockets, air-breathing thrust producing engines and marine propulsion systems. In addition to the complete transformation system each of the component processes such as combustion, compression and expansion must be studied if improvements are to be made.

04. Energy Utilization: Timely analytical studies in the various fields affecting power utilization are essential. New concepts and findings of basic research must be prudently examined and evaluated to pinpoint the earliest possible Naval usage. Optimum use of an energy source also requires that consideration be given to the goals to be achieved and the mission to be accomplished. Such critical problems as regulation and control must be given serious study.

III. Environmental Sciences 61245012-30

A. R009 Oceanography 61245012-31

01. Physical Oceanography: Understanding of the oceans and harbors is increased through studies of circulation; waves and tides; sea ice; bottom topography and submarine geology; physical and chemical properties of sea water; ocean-atmosphere energy exchange processes; measurement of sea-state and interaction patterns, and the time rate of change of these conditions; and the distribution of marine vegetation and ocean fish and animals.

02. Chemical Oceanography:

03. Marine Biology:

04. Marine Geophysics and Geochemistry:

B. R010 Terrestrial Sciences 61245012-32

01. Earth Physics: Knowledge about the structure, composition, geological history and the physical properties of the earth and the processes which are responsible for the characteristics of the earth's surface and its modification is gained through studies in geodesy, seismology, geochemistry, geology and measurements of gravity and the electronic and magnetic properties of the earth.

02. Geography: Geographic research concentrates mainly on the coastal areas and foreign lands. Investigations in the little known or foreign areas include studies of terrain, geology, soils, micro-climate, and plant, animal and human ecology. Studies of the geographic environment of coastal regions are designed to provide information on such elements as terrain, climate, vegetation, surf and near-shore features, and coastal processes, and to evolve improved, rapid and adaptable techniques for acquiring, evaluating and presenting coastal data. To improve means of acquiring geographic information, research is conducted on techniques of identification and interpretation of aerial photographs, and presentations of other sensor devices, such as radar.

03. Arctic Research: A broad program of research in the Arctic including such fields as oceanography, meteorology, geology, astrophysics, radio propagation, geomagnetism, seismology, gravity, environmental physiology, plant and animal ecology and geography.

04. Environmental Factors: Emphasis is placed on acquiring knowledge of the interrelationships between physical phenomena of Naval interest and the geophysical environment in which an operation is conducted. Information is obtained on the mitigating or enhancing effect of the environment in determining the offensive and defensive capability of weapons and weapons systems by studying the effects of various natural environments on energy coupling and transfer; as well as the reverse process of determining the changes produced.

C. R011 Atmospheric Sciences 61245012-33

01. Atmospheric and High Altitude Physics: Studies of atmospheric physics are concerned mainly with the application of the techniques of dynamic meteorology to the solution of the problem of atmospheric circulation, including both small-scale and large-scale anomalies; increasing our knowledge of cloud physics in order to better understand the mechanism of precipitation, as well as the origins of weather and climate so that these meteorological processes may be more accurately predicted. High altitude research deals with studies of the outer region of the earth's atmosphere not normally considered part of present-day meteorology. These studies are conducted primarily with the use of rockets and low-orbiting satellites and include observations of such conventional parameters as temperature, density, pressure, mean molecular weight, and gas and ionic composition. In addition, rocket observations include studies on night airglow, ultraviolet emission, x-ray and Lyman-alpha emissions of solar flares, and the x-ray emission from corona condensations. Studies of micrometeorites; infrared absorption by high-altitude water-vapor; distribution of ozone concentrations and the effect of incoming ultraviolet; are included in both rocket and satellite observations, where feasible.

D. R012 Space Science (Added to DRS Elements)

01. Astronomy and Astrophysics: The study of extraterrestrial objects and phenomena and the correlation of such phenomena with terrestrial events, including celestial mechanics, particularly in the solar system, astronomy, planetology, astro-ballistics, solar astrophysics, stellar and interstellar structure, stellar atmospheres, mechanism of energy release, and stellar evolution. Considerable emphasis is being placed on extending the range of wavelengths at which useful observations can be made, as by the development of radio astronomy, and on improving techniques and increasing the sensitivity of equipment used.

02. Radio Astronomy Instrumentation Studies: Investigation of refined instrumentation, including collectors, radiometers and data-reduction apparatus.

IV. Life Sciences 61245012-40

A. R013 Biological and Medical Sciences 61245012-41

01. Regulatory Mechanisms: Studies of the general laws of biological systems capable of regulating life processes. Investigations are conducted on humans or lower forms of life as required.

02. Immunology and Hematology: Studies of the biological processes related to immunity in living systems, including the blood and blood forming tissues. This effort will include work in the area of tissue and organ transplant not related to military needs.

03. Biological Response to Environment: Studies of the physiological responses to acute or chronic exposure to physical, chemical or biological stressors found in abnormal environments.

04. Microbiology: Studies of basic microbial mechanisms and influence in the environment, microbial genetics, and host parasite relationships. Includes investigations of: microbial decay, corrosion, contamination, and deterioration of materials.

05. Biochemistry: Studies of the properties, reactions and interactions of living systems with emphasis on energy transformations, properties of micromolecules, effects of environment factors and peculiarly marine metabolic processes.

06. Hydrobiology: Investigations of the relationships between the biological components of sea and fresh waters and the other factors of those environments. Particular emphasis is directed to identifying and characterizing the influences of the biological components of natural waters on physical phenomena and materials.

07. Biophysics: The study of physical phenomena in biological systems and the application of physical techniques and concepts to biological problems.

08. Epidemiology: Studies dealing with the relationships of the factors which determine the frequencies and distributions of infectious processes, diseases, or physiological states in a community.

09. Biological Orientation: Investigations of the mechanisms employed by a variety of living organisms to detect, identify, and travel towards distant objectives. This includes the mechanisms utilized by biological forms to convey and receive information.

10. Ecology: Research endeavoring to ascertain the biological factors of environmental and geographic situations. Particular emphasis is placed on the elucidation of fundamental data which is relevant to biological factors of natural environments. This also includes studies of the biological factors of the elements controlled through artificial changes in temperature, light, and other characteristics of the environment.

11. Neurology and Neuropsychiatry: Research which deals with disorders of the nervous systems or diseases of the mind.

12. Surgical Sciences: Research which deals with the art and science of surgery, including its specialities. This effort will include dentistry and its subspecialities, and surgical nursing.

13. Medical Sciences: Research which deals with the art and science of medicine, including its specialties. This effort will include medical nursing and its subspecialties.

14. Radiology, Pathology and Laboratory Sciences: Research which deals with the science of measuring, predicting, and evaluating biological functions related to the health and performance of living systems.

15. Pharmacology: Research which deals with the science of preparation, quality, uses and effects of drugs and biologicals.

B. R014 Behavioral and Social Sciences 61245012-42

01. Sensory Mechanisms: The functional capacities and operations of sensory systems as they receive and convert energies from the environment into neural energy.

02. Neural and Perceptual Processes: The translation, integration and differentiation of neural energy as the organism interprets its environment and the influence of pharmacological agents upon these functions with emphasis upon their enhancement.

03. Motor Mechanisms: The functional capacities and operation of motor systems as they receive and convert neural energy to response and adjustment.

04. Psychological Traits: Research aimed at the identification and measurement of psychological processes and the better understanding of individual differences through theoretical and methodological development.

05. Selection Methods and Performance Criteria: Methods for determining job requirements, selecting personnel, establishing criteria for performance evaluation, and establishing performance limits of men in man-machine systems.

06. Learning and Training: Basic investigations into the process of human learning and training methods used in shaping and modifying behavior.

07. Individual Effectiveness: Cognitive and motivational factors in individual-to-group interactions essential for individual effectiveness under different situations and environments.

08. Group Effectiveness: Intra-group and inter-group factors related to the effectiveness and morale of groups under normal, as well as stressful conditions.

09. Engineering Psychology: The application of established psychological and engineering principles to the design of systems (Human Engineering); providing a foundation of data related to man-machine systems.

APPENDIX B

PROPOSED CATEGORIES OF TECHNOLOGICAL CAPABILITIES (PART II)

Section 1 - Engineering Technologies

Section 2 - Surveillance

Section 3 - Command and Guidance

Section 4 - Navigation

Section 5 - Power Technology

Section 6 - Weapons Technology

Section 7 - Vehicles/Installations

Section 8 - Countermeasures

Section 9 - Supporting Technologies

Section 10 - Space Technology

Technological Area		Associated Current EDR	Proposed ED Element
	Section 1 - ENGINEERING TECHNOLOGIES		
1.1	Materials Technology		
1.1.1	Metallic Materials	F02001	2.01
1.1.2	Inorganic Non-Metallic Materials	F02002	2.02
1.1.3	Organic Materials	F02003	2.03
1.1.4	Composite Materials	F02004	2.04
1.1.5	Energy Conversion Materials	F02005	2.05
1.1.6	Fuels, Propellants and Lubricants		2.06
1.1.7	Structural Mechanics		2.07
1.2	Fluid Dynamics		
1.2.1	Aerodynamics		4.01
1.2.2	Hydrodynamics		4.02
1.2.3	Space Dynamics		4.03
1.3	Environment		
1.3.1	Meteorological Charting and Mapping	F00302	5.01
1.3.2	Geophysical-Geographic Charting and Mapping	F00303	5.01
1.3.3	Oceanographic-Hydrographic Charting	F00304	5.01
1.3.4	Astronautic-Celestial Charting	F00305	5.01
1.3.5	Meteorological Prediction	F00306	5.02
1.3.6	Geophysical-Geographic Prediction	F00307	5.02
1.3.7	Oceanographic-Hydrographic Prediction	F00308	5.02
1.3.8	Astronautic-Celestial Prediction	F00309	5.02
1.3.9	Weather Modification and Control	F00310	5.03

Technological Area		Associated Current EDR	Proposed ED Element
1.4	Acoustics		
1.4.1	Sound Propagation		6.01
1.4.2	Sound Sources	F00604	6.02
1.4.3	Sound Reception and Signal Processing	F00604	6.03
1.4.4	Noise and Noise Reduction		6.04
1.4.5	Components		6.07
1.5	Electromagnetics		
1.5.1	Electromagnetic Propagation		7.01
1.5.2	Transmission	F00602	7.02
1.5.3	Reception	F00602	7.03
1.5.4	Compatibility and Interference	F00609, F01315	7.04
1.5.5	Instrumentation		7.05
1.5.6	Components	F02102	7.07
1.5.7	Time and Frequency Control		7.08
1.5.8	Photography and Infrared		7.09
1.6	Information Processing and Presentation		
1.6.1	Data Processing	F00709	8.01
1.6.2	Displays		8.02
1.6.3	Pattern Recognition		8.03
1.6.4	Self-Organizing Systems		8.04
1.6.5	Data Storage and Retrieval	F00706	8.05
1.6.6	Programming		8.06
1.6.7	Input/Output	F00705	8.07
	Section 2 - SURVEILLANCE		
2.1	Surveillance Techniques and Devices		
2.1.1	Radar	F00102, F00802, F00902	
2.1.2	Sonar	F00103, F00113, F10804	
2.1.3	Optical	F00105	
2.1.4	Electro-Optical	F00105	
2.1.5	Photographic	F00104	
2.1.6	Television	F00107	
2.1.7	Magnetic, Electromagnetic, and Electrical Potential	F00106	
2.1.8	Electromagnetic Passive Interceptance Direction Finding	F00108	
2.1.9	Acoustic Passive Intercept and Direction Finding	F00109	
2.1.10	IFF and Classification	F00110	
2.1.11	Techniques to detect, identify and assess hazards from enemy attack	F01199	
2.1.12	Techniques for damage and casualty assessment		
	Section 3 - COMMAND AND GUIDANCE		13.01
3.1	External Communications	F00602, F00607	
3.1.1	Broadcast Communications		
3.1.2	Point to Point Communications		
3.1.3	Ship to Shore Communications		
3.1.4	Mobile to Mobile Communications		
3.1.5	Airborne Communications		
3.1.6	Submarine Communications		
3.2	Internal Communications	F00608, F00611	

Technological Area		Associated Current EDR	Proposed ED Element
3.3	Target Acquisition and Fire Control		
	3.3.1 Search, Target Detection, Classification		
	3.3.2 Target Identification		
	3.3.3 Integrated Surveillance	F00402	
	3.3.4 Weapon Fire Control	F00804, F10804, F00904	
	Section 4 - NAVIGATION		12.01
4.1	Inertial Navigation	F00202	
4.2	Dead Reckoning Navigation	F00203	
4.3	Celestial Navigation	F00204	
4.4	Magnetic Navigation	F00205	
4.5	Electromagnetic Navigation	F00206	
4.6	Optical and Infrared Navigation	F00207	
4.7	Beacons	F00208	
4.8	Doppler Navigation	F00210	
4.9	Gravity Navigation	F00211	
4.10	Aircraft Navigation	F00209, F00213	
4.11	Submarine Navigation	F00214	
4.12	Satellite Navigation	F00215	
4.13	Position Location		
	Section 5 - POWER TECHNOLOGY		
5.1	Primary Energy Conversion	F01306, F01403	3.01
	5.1.1 Primary and Secondary Batteries		
	5.1.2 Nuclear Reactors	F01316	
	5.1.3 Internal Combustion Engines		
	5.1.4 Fuel Cells		
5.2	Secondary Energy Conversion		3.02
	5.2.1 Turbines		
	5.2.2 Heat Exchangers		
	5.2.3 Thermoelectric Devices		
	5.2.4 Thermionic Devices		
5.3	Tertiary Energy Conversion	F01308	3.03
	5.3.1 Electric Generators		
	5.3.2 Electric Motors		
5.4	Energy Transmission and Storage	F01304	3.04
5.5	Thrust and Retarding Devices	F01307	3.05
	Section 6 - WEAPONS TECHNOLOGY		
6.1	Munitions		
	6.1.1 Explosives		1.01
	6.1.2 Warheads	F00808, F00908	1.03
	6.1.3 Fuzing	F00808, F00908	1.02
	6.1.4 Pyrotechnics	F00817	1.05
	6.1.5 Underwater Explosive Devices		1.06
	6.1.6 Cartridge Actuated Devices	F00817	1.07
	6.1.7 Kill Mechanisms		1.08
	6.1.8 Blast and Shock	F01310	1.04
	6.1.9 Nuclear Weapons and Effects	F01105	1.09
	6.1.10 Biological Weapons and Effects	F00880	1.09
	6.1.11 Chemical Weapons and Effects	F00880	1.09
	6.1.12 Adaption Kits		1.10

Technological Area	Associated Current EDR	Proposed ED Element
6.2 Guided Missiles		
6.2.1 Guidance	F00903	14.01
6.2.2 Launching	F00905	14.01
6.2.3 Propulsion	F00906	14.01
6.2.4 Structures	F00907	14.01
6.2.5 Homing Devices	F00909	14.01
6.2.6 Ballistics	F00910	14.01
6.2.7 Safety	F00912	14.01
6.2.8 Countermeasures	F00918	14.01
6.3 Underwater Weapons and Ordnance		
6.3.1 Guidance	F10803	14.01
6.3.2 Launching	F10805	14.01
6.3.3 Ballistics	F10809	14.01
6.3.4 Countermeasures Protection	F10819	14.01
6.4 Other Weapons and Ordnance		
6.4.1 Launching	F00805	14.01
6.4.2 Propulsion	F00806	14.01
6.4.3 Structures	F00807	14.01
6.4.4 Ballistics	F00809	14.01
6.4.5 Safety	F00811	14.01
6.4.6 Countermeasures Protection	F00819	14.01
6.5 Damage Assessment Techniques		
Section 7 - VEHICLES/INSTALLATIONS		16.01
7.1 Aircraft		
7.1.1 Structures (fixed wing, rotary)	F01202	
7.1.2 Aircraft Propulsion	F01203	
7.1.3 Aircraft Performance		
7.1.4 Controls and Instrumentation	F01204	
7.1.5 Ground Support	F01205	
7.1.6 Launching and Recovery	F01206	
7.1.7 Airborne Equipment	F01207	
7.1.8 Helicopter Support Equipment	F01501	
7.2 Surface and Underwater Vehicles		
7.2.1 Hull	F01302, F01402	
7.2.2 Structures	F01303, F01304, F01305, F01310, F01311	
7.2.3 Performances		
7.2.4 Control	F01309, F01404	
7.2.5 Electrical Equipment	F01312	
7.2.6 Habitability		
7.2.7 Damage Control		
7.2.8 Noise Reduction		
7.2.9 Amphibious Craft	F01406	
7.3 Support Elements		
7.3.1 Fuze and Ammunition Handling and Storage	F01505	
7.3.2 Crash, Fire Fighting and Decontamination	F01507	
7.3.3 Harbor Facilities	F01510	
7.3.4 Combat Engineering and Overseas Base Readiness and Recovery	F01511	
7.3.5 Armament Handling	F00818	
7.3.6 Mobile Support Groups		

Technological Area		Associated Current EDR	Proposed ED Element
	Section 8 - COUNTERMEASURES		15.01
8.1	Mine Defense	F01102	
8.2	Torpedo Defense	F01103	
8.3	Inshore Underseas Warfare	F01104	
8.4	Atomic Defense		
	8.4.1 Detection, Identification, Warning	F01105	
	8.4.2 Protection (personnel, equipment)		
	8.4.3 Material Decontamination and Restoration		
	8.4.4 Personnel Decontamination, Medical Support and Recovery		
8.5	Biological and Chemical Defense	F01108	
	8.5.1 Detection, Identification, Warning		
	8.5.2 Protection (personnel, equipment)	F01580	
	8.5.3 Material Decontamination and Restoration		
	8.5.4 Personnel Decontamination, Medical Support and Recovery		
8.6	Electromagnetic Countermeasures and Counter-Countermeasures	F01002	7.06
	8.6.1 Passive ECM		
	8.6.2 Active ECM		
8.7	Infrared and Visual Countermeasures	F01003	
8.8	Acoustic Countermeasures and Counter-Countermeasures	F01004	6.06
8.9	Underwater Demolition Team Equipment	F01006	
8.10	Anti-Mechanized Defense	F01007	
8.11	Explosive Ordnance Disposal	F01109	
	Section 9 - SUPPORTING TECHNOLOGIES		
9.1	Logistics Support		
	9.1.1 Packaging	F01503	10.01
	9.1.2 Stowage and Storage	F01504	10.02
	9.1.3 Protective Coverings		10.03
	9.1.4 Materials Handling	F01508	10.04
	9.1.5 Facilities Maintenance and Repair	F01506	10.05
	9.1.6 Quartering and Messing	F01513	10.06
	9.1.7 Procurement and Distribution	F01502	10.07
9.2	Biological and Behavioral Technologies		
	9.2.1 Personnel Requirements and Billet Analysis	F01602	9.01
	9.2.2 Personnel Selection, Assessment and Utilization	F01604, F01605, F01606	9.02
	9.2.3 Training Requirements, Programs and Devices	F01702, F01703, F01704, F01799	9.03
	9.2.4 Administration and Data Management	F01603, F01607, F01608	9.04
	9.2.5 Environmental Biology	F01210	9.05
	9.2.6 Medical Technology, Operational and Clinical Medicine	F02203, F02204	9.06

Technological Area	Associated Current EDR	Proposed ED Element
9.2 Biological and Behavioral Technologies—Continued		
9.2.7 Life Support and Safety	F02202	9.07
9.2.8 Clothing and Protection of Personnel	F01580, F01514	
9.2.9 Human Performance	F02202	9.08
9.2.10 Behavioral, Social and Economic Factors		9.09
Section 10 - SPACE TECHNOLOGY		
10.1 Satellite Applications	F01902	
10.1.1 Sea Surveillance		
10.1.2 Navigation		
10.1.3 Meteorological Observations		
10.1.4 Reconnaissance		
10.1.5 Oceanography		
10.1.6 Communications		
10.2 Astronautics Defense	F01903	
10.3 Mobile Sea Launch	F01904	
10.4 Manned Space Flight Applications	F01905	
10.5 Probe Applications	F01906	

DESCRIPTION OF EXPLORATORY DEVELOPMENT ELEMENTS

MATERIALS AND STRUCTURES

Covers properties, manufacture, fabrication, and environmental protection of materials. All types of materials are included, such as metals, alloys, ceramics, plastics, composites, etc. Fabrication includes welding, joining, shaping, etc. Also, included are fuels, propellants and their oxydizers, lubricants, hydraulic fluids, and their containment. Also included are the applications of materials to structures and the theory and development of the means for dynamic structural design.

Excluded are: the applications of materials (see specific area); the design of tests (see "Systems Effectiveness"); explosives, pyrotechnics, and incendiary materials (see "Munitions and Effects"); and the mechanical handling of materials such as pumping (see "Power").

Metallic Materials: Encompasses the investigation and development of the properties, fabrication and processes, inspection, test and analysis, and environmental protection of metallic materials and their alloys.

Inorganic Non-Metallic Materials: Encompasses the investigation and development of the properties, fabrication and processes, inspection, test and analysis, and environmental protection of ceramics, graphitics and silicates, and other inorganic non-metallic materials in such forms as films, coatings or bodies. This includes such materials as glass, porcelain, brick, tile, enamels, ferroelectrics, refractories, and the like.

Organic Materials: Encompasses the investigation and development of the properties, fabrication and processes, inspection, test and analysis, and environmental protection of plastics, elastomers, wood, cordage, leathers, adhesives, sealing compounds, polymers based on organic metallics, and other organic materials.

Composite Materials: Encompasses the investigation and development of the properties, fabrication and processes, inspection, test and analysis, and environmental protection of composite materials such as glass, reinforced plastics, laminates and sandwich materials. Also, in general, studies of individual components of composite materials which are undertaken for the distinct purposes of improving the composite materials as such are included.

Energy Conversion Materials: Encompasses the investigation and development of the properties, fabrication and processes, inspection, test and analysis, and environmental protection of energy conversion materials such as thermionic, fuel cell, plasmadynamic, thermoelectric, and related techniques for the direct conversion of thermal or chemical energy to electrical energy.

Fuels, Propellants, and Lubricants: Encompasses the investigation and development of the properties, fabrication and processes, inspection, test and analysis, and environmental protection of fuels, propellants, and lubricants such as combustibles, ignitables (except explosives) and the like.

Structural Mechanics: Encompasses all aspects of the applications of materials to structures and the theories and development of the means for dynamic structural design. Also included is the application of available techniques to the physical framework which contains the various parts of a complete vehicle. Included within the framework are such items as control surfaces, ablation shells, enclosures, etc.

FLUID DYNAMICS

Treats of the dynamic interaction between the vehicle and its media including aerospace. Included are the motions, forces, thermal, gravity, inertial, and other effects due to the media-vehicle interaction with air, water, and air/water interface. Included are phenomena away from the body as well as at the body surface. Also included are the aerodynamic or hydrodynamic surfaces and their mechanical controls.

Excluded are: the independent physical properties and behavior of aerospace, air/water interface and water without the presence of vehicular bodies (see "Environment"); and hydraulics, pneumatics, pumps, and propulsive systems (see "Power").

Aerodynamics: Investigations of aerodynamic phenomena such as aeroelasticity, stability and control, drag, performance, heat transfer, aerophysics, surface-effect phenomena, etc., on full scale or model size vehicles.

Hydrodynamics: Investigations of hydrodynamic phenomena such as hydroelasticity, boundary layers, stability and control, drag, performance, surface effect phenomena, etc., on full scale or model size vehicles.

Space Dynamics: Investigations of the effects of the physical space environment on space vehicles, mechanics of satellite orbit, etc.

ENVIRONMENT

Included are the independent physical properties of the spaces and interfaces - subsurface, surface, and aerospace. It also contains seismic and weather phenomena including efforts at weather control.

Excluded are: the motions of the fluid media about vehicular bodies (see "Fluid Dynamics"); and the life within the environment (see "Biological and Behavioral Technologies").

Survey: Provide means for the sensing, measuring, and recording of properties and mechanisms within and between the land-hydro-aero-outer spaces.

Prediction: Provides methods for the integration, analysis, and utilization of gathered data for the prediction and confirmation of environmental conditions and their variance in space and time.

Control: Determines means for the change, influence, or prevention of the natural state or variance of environmental phenomena.

ACOUSTICS

Includes the generation, propagation, reception, perception, measurement, reproduction and characteristics of acoustic energy in any media. Environmental effects are included. Included are active and passive devices with their transducers, signal processing and counter-countermeasures.

Excluded are: the independent properties of the media (see "Environment"); associated computers and displays (see "Information Processing and Presentation"); transmission by radio (see "Electromagnetics"), explosives for echo ranging (see "Munitions and Effects"), and ordinary vibrations and fluid elastic effects (see "Materials and Structures").

Sound Propagation: Encompasses all aspects of the direct transmission of acoustic energy through a medium. It includes the theories and measurements of radiation, absorption, scattering, refraction, reflection, and diffraction of the signals in the acoustic portions of the frequency spectrum.

Sound Sources: Encompasses all aspects of techniques and methods to generate and radiate acoustic waves such as transducers, their design, and the impedance matching to the medium.

Sound Reception and Signal Processing: Encompasses all aspects of the methods and techniques of reception, perception, classification, echoes, reflectivity, and interference of acoustic waves and their conversion to useful signals.

Noise and Noise Reduction: Encompasses all aspects of noise measurement, analysis, and source (ambient, self-generated, radiated, etc.), for the purpose of reducting the radiation and interference.

Components: Encompasses the improvement, efficiency, and environmental conditions of old, or the introduction of new, elements and devices as tools for the achievement of acoustic functions.

ELECTROMAGNETICS

Includes the generation, propagation, reception, perception, measurement, reproduction and characteristics of electromagnetic energy in any media. Environmental effects are included. Also included are active and passive devices with their antennae, signal processing and counter-countermeasures, all devices which depend on the properties of electron shells, such as transistors, photo detectors, Hall effects, lasers, spin magnetometers, etc. Included are vidicons, photography and the photographic processes, and the development and application of video, optical, and infrared sensors. For convenience, thin film assemblages are also contained in this group as are the devices like resistive strain gauges.

Excluded are: the independent properties of the media (see "Environment"); and the displays and interpretations (see "Information Processing and Presentation").

Electromagnetic Propagation: Encompasses all aspects of the direct transmission of electromagnetic energy through a medium. It includes the theories and measurements of radiation, absorption, scattering, reflection and diffraction of the signal in the electromagnetic portions of the frequency spectrum.

Transmission: Encompasses all means to generate and radiate electromagnetic waves and their conversion from useful electric signals.

Reception: Encompasses all aspects of the reception of electromagnetic waves and their conversion to useful electric signals.

Compatibility and Interference: Includes those efforts which measure and study the interactions among components and equipments using the electromagnetic spectrum and aims at reducing problems of matching and mis-matching contiguous functions.

Instrumentation: Encompasses all techniques and methods used to collect factual data on electromagnetic measurements, equipment, and the calibration of equipment.

Components: Encompasses the improvement, efficiency, and environmental conditions of old, or the introduction of new, circuitry elements and devices as tools for the achievement of electronic functions such as antennae, tubes, oscillators, undulators, capacitors, inductors, resistors, and the like.

Time and Frequency Control: Includes the correlation and reference means for uniform control of wave propagation and the time related functions.

Photography and Infrared: Encompasses all aspects of the use of visual, optical, photographic, photographic processes, and infrared techniques for the collection of information and data.

INFORMATION PROCESSING AND PRESENTATION

Includes computer technology and the processing of data for command/control and for control/guidance. Included are encoders and means for photographic interpretation, visual and auditory displays. Involved are items such as meters, indicators and amplifiers.

Excluded are: the signal processing, such as signal to noise enhancement (see "Acoustics" or "Electromagnetics"); the radio links to transmit data (see "Electromagnetics"); and the man/machine interface problems (see "Biological and Behavioral Technologies").

Data Processing: Encompasses all operations upon data including such operations as data acquisition, handling, and evaluation.

Displays: Encompasses all aspects of the presentation of information in a way that it may be perceived by a human observer.

Pattern Recognition: Deals with the processes of identifying given input data as belonging to an appropriate class or category of input signals.

Self-Organizing Systems: Encompasses all methods and processes used to develop systems that modify their internal structure as a function of their experience and environment.

Data Storage and Retrieval: Encompasses all the techniques and methods of data storage and retrieval such as storage capacity, access speed, identification and tagging of information, storage organization, and strategy of search.

Programming: Encompasses the means and processes of setting down in proper order the sequence of operations a computer is to follow in solving any given problem.

Input/Output: Encompasses all methods of developing components which permit men and sensors to communicate with machines including non-mechanical methods as direct voice input.

SURVEILLANCE

Includes development of requirements for, analyses of, technical approaches to and evaluative equipment for the gathering and generation of required information, including: detection, location and classification of targets and reference points; collection of environmental and intelligence data; reconnaissance; channel marking, timing, surveying, tracking, charting, etc.

COMMAND AND GUIDANCE

Includes development of requirements for, analyses of, technical approaches to and evaluative equipment for the integration, evaluation, relay and application display of information, including: communication; fire control; vehicle control; security, homing, data links, command stations, etc.

POWER

Includes all energy conversion devices for power and their electrical and mechanical parts such as rockets, gas turbines, pistons, ramjets, jets, propellers, magnetohydrodynamics, ion propulsion, etc. Also included are: techniques associated with generators, batteries, distribution and regulation for electrical power as well as hydraulics, pneumatics, pumps, and plumbing. Techniques associated with catapults, arresting gears, missile launchers, and guns are also included. All associated controls are also included.

Excluded are: sensors (see "Electromagnetics"); instruments (see "Information Processing and Presentation"); and fuels and oxydizers (see "Materials and Structures").

Primary Energy Conversion: Encompasses the investigation and development of items such as batteries, combustion equipment, reactors, internal combustion engines, fuel cells, rockets, and the like.

Secondary Energy Conversion: Encompasses the investigation and development of items such as turbines, heat exchangers, thermoelectric, boilers, and the like.

Tertiary Energy Conversion: Encompasses the investigation and development of items such as pumps, blowers, motors, generators, air induction, accessories, and the like.

Energy Transmission and Storage: Encompasses the investigation and development of items such as piping, valves, shafting, gear boxes and drives, clutches, wiring, switches, transformers, fuel tankage, accumulators, regulators, hydraulics, pneumatics and the like.

Thrust and Retarding Devices: Encompasses the investigation and development of items such as jets, propellers, traction devices, catapults, launchers, tubes, drags, brakes, arrestors and the like.

MUNITIONS

The composition, safety, handling, stowage, storage, manufacture and disposal of explosives. Included are effects such as blast, shock, overpressures, and the coupling between warhead and explosive and the response of targets. Included are: all of the kill mechanisms; warheads; fusing; arming; adaption kits for A/B/C warheads; and direct support of work on A/B/C agents. Pyrotechnics and explosives for underwater sound sources are also included. The above is non-nuclear. The nuclear work under this section is limited to blast, pressure, shock, and thermal effects on, and the response of, targets.

Excluded are: the radiation, thermal, and blast effects on humans (see "Biological and Behavioral Technologies").

Explosives: Encompasses all aspects of the characteristics of explosives, effects of constituents, shape, confinement, and the like.

Warheads: Includes all aspects of the non-nuclear warheads for all types of targets such as penetrating, incendiary, fragmentation, and shaped charge warheads.

Fuzing: Encompasses all aspects of fuzes including such items as proximity, impact, mechanical and electrical time fuzes, mine mechanisms, safety and arming, and sterilization.

Pyrotechnics: Encompasses all aspects of the characteristics of explosives or rapidly burning material for other than power purposes such as flares, identification signals, and color bursts.

Underwater Explosive Devices: Encompasses all aspects of explosives used as underwater sound sources such as Explosive Echo Ranging devices.

Cartridge Actuated Devices: Encompasses all aspects of cartridge devices for auxiliary power, cockpit ejection, explosive switches and the like.

Kill Mechanisms: Encompasses all types of kill mechanisms, other than warheads, used to kill or nullify targets.

Blast & Shock: Encompasses all aspects of the blast, overpressure, and shock characteristics and its effects on materials, vehicles, equipment, or targets.

Nuclear Weapons and Effects: Encompasses all research and development work in direct support of nuclear weapons.

Biological Weapons and Effects: Encompasses all research and development work in direct support of biological agents.

Chemical Weapons and Effects: Encompasses all research and development work in direct support of chemical agents.

Adaption Kits: This EDP includes all aspects of the development of adaption kits for nuclear warheads, biological and chemical agents.

GUIDED MISSILES

Includes development of requirements for, analyses of, technical approaches to and evaluative equipment for the destruction, incapacitation or determent of enemy military or support capabilities.

UNDERWATER WEAPONS AND ORDNANCE

Includes development of requirements for, analyses of, technical approaches to and evaluative equipment for the destruction, incapacitation or determent of enemy military or support capabilities.

OTHER WEAPONS AND ORDNANCE

Includes development of requirements for, analyses of, technical approaches to and evaluative equipment for the destruction, incapacitation or determent of enemy military or support capabilities.

VEHICLES INSTALLATIONS

Includes development of requirements for, analyses of technical approaches to and evaluative equipment for the provision, operation, and maintenance of vehicles or facilities for direct effective application of the other functional elements in the Naval environmental and military situations, including: structures, (afloat, airborne, and ashore), propulsion, utilities, environmental protection, fire protection, silencing, mooring, damage control, cable laying, shipbuilding, facilities construction, physical security, material and personnel transport, amphibious force equipment and boats and construction battalion equipment.

COUNTERMEASURES

Includes development of requirements for, analyses of, technical approaches to and evaluative equipment for active and passive protection against, prevention of, and nullification action toward effectiveness of expendable enemy weapons and influences, including: mine (sweeping and hunting); torpedo countermeasures; A/B/C defense, jamming and deception; protective barriers, arrangements and devices; decontamination, isolation, armor, concealment, degaussing, UDT, etc.

Electromagnetic Countermeasures and Counter-Countermeasures: Encompasses applied research and development in electromagnetic jamming and deception. Projects should provide means to reduce and degrade the effectiveness of enemy electromagnetic radiating devices. Also included are means to reduce or eliminate enemy countermeasures.

Acoustic Countermeasures and Counter-Countermeasures: Encompasses applied research and development in acoustic jamming and deception. It provides means to reduce the effectiveness of enemy acoustic radiating devices; and to reduce or eliminate enemy countermeasure devices.

LOGISTICS SUPPORT

Included are packaging, handling, transportation requirements and storage of materials and equipments. Included are the development of capabilities for providing facilities such as advanced base, harbor, shore, over-the-beach, and ocean terminals. Also, the development of: personnel protection and clothing; quartering, messing; food service operations; utilities and services; and maintenance and repair capabilities. Logistic analysis studies and tests which encompass repair parts/allowances and load list formulation are included.

Excluded are: factors of survival, safety and accident prevention (see "Biological and Behavioral Technologies").

Packaging: Includes all work on methods, techniques, equipments, etc., for improving such things as protective packaging, marking, and environmental protection. It also includes work on methods to save space, reduce cost, and improve packing.

Stowage and Storage: Deals with the study of the storage and stowage of materials such as ammunition and petroleum. Includes studies of environmental stowage storage and space savings.

Protective Coverings: Encompasses all research and development to improve the protection of personnel and equipments.

Materials Handling: Encompasses the effort to develop methods and techniques of materials handling including the study of conveyer and lift devices, etc.

Facilities Construction and Maintenance: Encompasses the construction and maintenance of facilities. Included are material development and techniques for construction and maintenance of advanced bases, harbor, ocean terminals, shipyards, material storage, hospitals, utilities, and transportation, ashore and for fixed ocean facilities. Excluded are: the techniques pertinent to materials, energy conversion, fuels, lubricants, structural mechanics, power conversion, energy transmission and storage, and thrust and retarding devices.

Quartering and Messing: Encompasses all shore based quartering and messing facilities including the effects of such items as food handling, environment, comfort, space, cost, and nutritional value/life.

BIOLOGICAL AND BEHAVIORAL TECHNOLOGIES

Includes efforts in the development of advancements and improvements in personnel selection and administration and manpower management including the determination of numbers requirements; skill identification, testing and requirements; personnel career planning and performance assessment; man-machine performance matching; and factors involved in enlistment, volunteering, motivation and morals. It shall include efforts that will result in criteria for new and improved training programs, techniques and devices.

Included are efforts in the operational and clinical medical specialties for the development of new and improved methods of medical, surgical and dental therapy; preventive and occupational medicine techniques; medical logistic and professional support of operational combatant and support personnel; and the development of information leading to physical, psychophysiological and neuropsychiatric criteria for selection, training and management of personnel.

Included are efforts to establish the psychophysiological factors and human response to routine and hazardous stresses leading to conceptual methods of control and display; life support, escape and survival systems; and for the development of prophylactic and performance enhancement pharmaceuticals. It shall include efforts to identify physical, behavioral, social and economic factors of warring populations.

Included are: efforts concerned with the detection, identification, controlling and/or utilization of pertinent biological components of all operating environments.

Excluded are: efforts for the development of personnel protective equipment and clothing (see "Logistics and Support").

Personnel Requirements and Billet Analysis: Efforts will result in means to determine personnel requirements by skill identification and billet analysis and will develop means of optimum matching of human performance to conceptual systems.

Personnel Selection Assessment and Utilization: Encompasses the development of information leading to improved selection criteria; screening techniques; procurement and separation standards; performance assessment and career planning, and in the determination of motivation and morale factors. It shall include efforts to define factors of crew-interaction, teamwork and leadership.

Training Requirements, Programs and Devices: Encompasses the definition of conceptual systems characteristics and associated personnel training requirements. Includes the study and development of new techniques, methods, devices and aids aimed at improving and maintaining effectiveness of operational and maintenance personnel.

Administrative and Data Management: Includes study and evaluation of new and advanced concepts and methods of personnel administration and manpower management. Determine the characteristic of new techniques for the reporting, processing and utilization of personnel data.

Environmental Biology: Encompasses the studies involved in the detecting, identifying, controlling and/or utilizing the peculiar biological components of operating environments. (Concerns the characteristics, effects, and possible utilization of all living organisms, plant and animal, with the exception of man, relative to systems operations).

Medical Technology Operational and Clinical Medicine: Includes efforts in operational, clinical, and preventive medical specialties. Includes studies for new prophylactic, therapeutic and medical logistic methods and techniques for personnel protection and treatment.

Studies will lead to information required for establishing physical, psychophysiological and neuropsychiatric criteria for selection, training and management of personnel.

Life Support and Safety: Encompasses efforts to understand the psychophysiological factors and to establish man's response and tolerance to routine, hazardous and emergency stresses required for the development of future life support and survival systems. Includes the development of protective and performance enhancement agents. Excluded is the development of personnel support and protective equipment and clothing.

Clothing and Protection of Personnel: Encompasses all research and development to improve the clothing and protection of personnel. Includes the study of clothing for environmental protection, AW/BW/CW protection, fire-fighting protective clothing, etc.

Human Performance: Includes studies of the perception and response capabilities and limitations of man relative to future systems. Includes criteria development for future control and display systems and for determining interface functions and optimal utilization of man in the man-machine complex. Excluded is the design and development of control and display systems and components.

Behavioral, Social and Economic Factors: Includes studies into the effects of all types of warfare upon native populations of warring nations. Studies include the social and economic impact on the physical and psychologic status of populations during periods of conflict, as well as means for the development of special warfare and counterinsurgency techniques and for the postwar management of defeated nations.

APPENDIX C

SOURCES OF INFORMATION

Domestic

AIR FORCE

Air Force Headquarters, Pentagon - Washington, D. C.
Air Force Systems Command, Headquarters (HQ, AFSC) - Andrews AFB, Maryland
Research and Technology Division - Bolling Field, Washington, D. C.
Flight Dynamics Laboratory (FDL) - Wright-Patterson AFB, Ohio
Aerospace Systems Division (ASD) - Wright-Patterson AFB, Ohio
Space Systems Division (SSD) - Inglewood, California
Electronic Systems Division (ESD) - Hanscom Field, Massachusetts
Office of Aerospace Research, Headquarters (HQ, OAR) - Arlington, Va.
Aeronautical Research Laboratory (ARL) - Wright-Patterson AFB, Ohio
Cambridge Research Laboratory (CRL) - Cambridge, Massachusetts
Air Force Office of Scientific Research (AFOSR) - Arlington, Virginia
Advanced Planning Board - Wester Test Range, Vandenberg AFB
Air Force Academy - Colorado Springs, Colorado

ARMY

Army Headquarters Staff - Pentagon, Washington, D. C.
Army Combat Development Command Headquarters (HQ, CDC) - Fort Belvoir, Va.
Army Research Office (ARO) Arlington, Virginia
Army Materiel Command, Headquarters (HQ, AMC) - Baileys Crossroads, Virginia
Engineering Research and Development Laboratory (ERDL) - Fort Belvoir, Virginia
Dugway Proving Grounds (DPG) - Dugway, Utah
Electronics Research and Development Laboratory - Fort Monmouth, New Jersey
Army Chemical Center - Edgewood Arsenal, Maryland
Army Materiel Research Laboratory - Watertown Arsenal, New York
Biological Laboratory - Fort Detrick, Frederick, Maryland
Army Missile Command - Red Stone Arsenal, Huntsville, Alabama
Ballistics Research Laboratory - Aberdeen Proving Grounds, Maryland
Human Engineering Laboratory - Aberdeen Proving Grounds, Maryland
Coating and Chemical Laboratory - Aberdeen Proving Grounds, Maryland

NAVY

Assistant Secretary of the Navy (Research & Development) - Pentagon, Washington, D. C.
Chief of Naval Operations (CNO) - Pentagon, Washington, D. C.
Headquarters, Naval Material Command (HQ, NMC) - Washington, D. C.
Chief of Naval Development (CND) - Washington, D. C.
Office of Naval Research (ONR) - Washington, D. C.
Center for Naval Analyses (CNA) - Arlington, Virginia
Naval Air Systems Command (NAVAIR) - Washington, D. C.
Naval Ordnance Systems Command (NAVORD) - Washington, D. C.
Naval Ship Systems Command (NAVSHIP) - Washington, D. C.
Naval Supply Systems Command (NAVSUP) - Washington, D. C.
Bureau of Naval Personnel (BUPERS) - Washington, D. C.
Bureau of Medicine and Surgery (BUMED) - Washington, D. C.

Naval Research Laboratory (NRL) - Washington, D. C.
Navy Marine Engineering Laboratory (MEL) - Annapolis, Maryland
Naval Ordnance Laboratory (NOL) - White Oak, Maryland
Naval Weapons Laboratory (NWL) - Dahlgren, Virginia
David Taylor Model Basin (DATMOBAS) - Washington, D. C.
Naval Applied Science Laboratory (NAVAPLSCIENLAB) - Brooklyn, New York
Navy Electronics Laboratory (NEL) - San Diego, California
Naval Air Engineering Center (NAVAIRENGCEN) - Philadelphia, Pennsylvania
Naval Medical Research Institute (NAVMEDRSCHINSTITUTE) - Bethesda, Maryland
Navy Mine Defense Laboratory (NAVMINDEFLAB) - Panama City, Florida
Naval Underwater Weapons Research and Engineering Station - Newport, Rhode Island
Naval Personnel Research Activity (NAVPERSRSCHACT) - San Diego, California
Naval Air Development Center (NAVAIRDEVCEN) - Johnsville, Pennsylvania
Naval Supply Research and Development Facility (NAVSUPRANDFAC) - Bayonne, N. J.
Naval Civil Engineering Laboratory (CIVENGRLAB) - Port Hueneme, California
Naval Training Device Center (NAVTRADEVCEN) - Orlando, Florida
Navy Underwater Sound Laboratory (NAVUWTRSOUNDLAB) - New London, Connecticut
Naval Oceanographic Office (NAVOCEANO) - Washington, D. C.

MARINE CORPS

Marine Corps Headquarters (HQ, MC) - Washington, D. C.
Long Range Study Panel - Quantico, Virginia

INDUSTRY

ABT Associates, Inc. - Cambridge, Massachusetts
Air, Inc. - Annapolis, Maryland
Bell Telephone Labs - Murray Hill, New Jersey
Battelle Memorial Institute - Washington, D. C.
Charles Pfizer Co. - Groton, Connecticut
Computer Command & Control Co. - Philadelphia, Pennsylvania
Communications Systems, Inc. - Paramus, New Jersey
Electric Boat Division, General Dynamics - Groton, Connecticut
G.E. Tempo - Santa Barbara, California
Hudson Institute - Harmon on Hudson, New York
E.I. duPont de Nemours and Company - Wilmington, Delaware
International Business Machines, Corporate Office - Rockville, Maryland
Litton, Inc. - Woodland Hills, California
Lockheed Missiles and Space Corporation - Palo Alto, California
Minneapolis-Honeywell, Military and Space Sciences Department - Washington, D. C.
Minnesota Mining and Manufacturing Co. - Washington, D. C.
Mitre Corporation - Hanscom Field, Massachusetts
National Security Industrial Association, National Headquarters - Washington, D. C.
North American Aviation, Corporate Offices - El Segundo, California
Rand Corporation - Santa Monica, California
RCA - Princeton, New Jersey
Research Analysis Corporation - McLean, Virginia
Space Technology Laboratories - Thompson-Ramo-Wooldridge - Space Park, California
Spindletop (Spindletop Research) - Lexington, Kentucky
Stanford Research Institute - Menlo Park, California
Xerox (Electro-Optical Systems, Inc.) - Pasadena, California

OTHER GOVERNMENT AGENCIES

Central Intelligence Agency
Atomic Energy Commission - Germantown, Maryland
Department of Commerce - Washington, D. C.

Headquarters, Federal Aviation Administration - Washington, D. C.
Headquarters, National Aeronautical Space Administration - Washington, D. C.
National Science Foundation - Washington, D. C.
Office of Emergency Planning - Washington, D. C.

FOREIGN

BRITISH EMBASSY

Head of Defence Research and Development Staff
Director, Guided Weapons and Electronics Group
Director, Aircraft Group
Assistant Director, Munitions Group

FRENCH EMBASSY

Military Attache
Assistant Air Attache
Assistant Naval Attache
Assistant Military Attache

INTERNATIONAL

Organization for Economic Cooperation and Development

APPENDIX D

METHODS OF GENERATING FORECAST DATA

Many methods of compiling the forecast are possible. During its tenure, the Navy Technological Forecasting Study Group considered five different methods along with a combination of the methods. Following is a description of the methods considered. The advantages and disadvantages of each are shown in Table D-1.

a. Technical Panels, a series of panels in the various scientific disciplines, technologies and functional areas, in which the experts in these categories would meet regularly to prepare the initial Naval forecast and to update it. The designated panel chairman would be responsible for selecting the panel membership and for preparing the final forecast entry in accordance with the forecasting schedule.

b. Principal Laboratories, in which assignment of specific disciplines, technologies and functions would be made to the laboratory having the greatest expertise in the specific area. The laboratory would be responsible for preparing the final forecast entry in accordance with the forecasting schedule and for this purpose would draw on the experience of the other Naval laboratories engaged in the area as well as that of all segments of the technical community.

c. Individual Laboratories, in which each laboratory would submit, as part of an updated laboratory long-range plan, a forecast in each discipline and technology covered by its mission. The principal forecast offices (ONR and NAVMAT) would be responsible for integrating the individual inputs into the Naval Technological Forecast.

d. Technical Workshops, small studies organized to bring together the knowledgeable personnel in the fields of science and technology under review. In small groups, they would resemble technical panels, in larger groups they would be comparable to the Naval Technical Workshops and the Technology Needs Identification Studies. Directed to finding a solution or series of solutions to problems of concern to the Navy, they could include panels on threat, policy and military considerations, capabilities, and technologies. Having projected the state-of-the-art in advance, the panels would interact at the workshop to find the solution or solutions to the problem under study. The principal forecast office would be responsible for the workshop. Panel members would be drawn not only from the laboratories and technical offices of ONR, NAVMAT and the Systems Commands, but from the entire technical community.

e. Higher Management Direction, very similar to the Principal Laboratory method, but making a higher management level responsible for the forecast. The scientific branches of ONR, the technical offices of NAVMAT and of the Systems Commands, who are charged with the direction of the Naval RDT&E effort in a given technical area, would be responsible for generating the forecast in that area. Whereas it is expected that most of the data would be drawn from the Naval laboratories, the larger technical community could contribute significantly to the forecast.

f. A Combination of Two or More of These Methods, may be desirable to combine two or more of these methods. The advantages and disadvantages of the several methods are outlined in Appendix D.

Table D-1
Methods of Generating Forecast Data

Method	Advantages	Disadvantages
Technical Panels	Requires smaller headquarters staff.	Requires time of many people.
	Individuals are responsible for forecast.	Success in large part is dependent on head of panel.
	Lends itself to interservice forecasting.	May have high bias.
	Aids in distributing forecasting load.	Communication problems.
	Easier to bring in outsiders.	Possible loss of organizational support.
	Technical people prepare forecast.	
Principal Laboratories	Requires smaller headquarters staff.	May place heavy load on some laboratories.
	Gives broader base for responsibility.	Minor role for smaller laboratories.
	Reduced need for technical panels.	May be prepared by laboratory staff personnel.
	Laboratory is responsible, insuring organizational support.	
Individual Laboratories	No need for specific assignments.	Larger headquarters staff may be required.
	Each laboratory is responsible.	Loss of personal contact.
	Possible lower cost to laboratories.	Possible duplication.
Technical Workshops	Good for systems.	Considerable time required.
	Good for identifying technological needs.	Dependent on availability of individuals.
	Threat and capability inputs possible.	
Higher Management Direction	Easy to include outsiders.	Industry emphasis.
	Broad base responsibility.	Bias may appear.
	Political acceptability.	
A Combination of Two or More of These Methods		Possible complications in responsibilities.

APPENDIX E

BIBLIOGRAPHY

Several reports pertaining to forecasting and long-range planning came to the attention of the Forecasting Group. Relevant reports which may be of interest to the reader are listed below. The listing must not be considered to be exhaustive. When available, either the author's abstract or the Group's appraisal of the report is included. Finally, the security classification of the report is indicated.

1. "Technological Forecasting," second edition, R. C. Lenz, Jr., Aeronautical Systems Division, AFSC, Wright-Patterson AFB, Ohio, ASD-TDR-62-414, June 1962. (Unclassified)

   Presents several methods of forecasting rates of technological advance. The methods include forecasting by extrapolation of existing rates; by analogies to biological growth processes; by precursive events; by derivation from primary trends; by interpretation of trend characteristics; and by dynamic simulation of the process of technological improvement. The investigation included a search of the literature for references to principles of technological progress and for methods which have been used for predictive purposes.

2. "Guidebook - Technological Forecasting," Research Planning Division, Army Research Office, Arlington, Va., July 1962. (Unclassified)

   Presents techniques and modes of expression to aid those responsible for preparing technological forecasts in the Army.

3. "Technological Forecasting in Perspective," unpublished paper by R. S. Isenson. (Unclassified)

   Discusses primarily forecasting methodology. There is a reference list at the end of the paper.

4. "Technological Forecasting: A Planning Tool," paper presented at Multi-National Corporate Planning Seminar, Fontainebleau-Avon, France, by R. S. Isenson, September 1964. (Unclassified)

   Discusses the rationale of technological forecasting, its usefulness, and methodologies. Gives general discussion of technological forecasting.

5. "Navy Long Range Strategic Study (NLRSS)-73," prepared by Strategic Plans Division (Op-60), Chief of Naval Operations, 9 May 1965. (SECRET)

6. "Navy Mid-Range Objectives Through 1975 Under Limited Funding Assumptions (MRO-75)," prepared by Long Range Objectives Group (Op-93), Chief of Naval Operations, 1 June 1964. (SECRET)

7. "Bureau of Naval Weapons Research and Development Planning Guide," Plans Division RDT&E, BuWeps, 1 July 1963. (SECRET)

8. "Bureau of Ships Long Range Plan for Research and Development (LRP-62)," Vol. IA (CONFIDENTIAL), Vol. IB (SECRET), Vol. IC (CONFIDENTIAL); Department of the Navy, Washington, D. C., August 1962.

9. "Rationales for Goals in Part I - The Undersea Target of Goals for Technology in Exploratory Development," Draft report, Chief of Naval Development (MAT 311), dated 31 August 1965. (SECRET)

Gives rationales used in deriving the Goals for Technology in Exploratory Development.

10. "Goals for Technology in Exploratory Development - The Undersea Target," Preliminary report published by the Chief of Naval Development (MAT 311), dated 31 August 1965. (SECRET)

Purpose is to assist in formulating the Exploratory Development Program of the Navy. The goals included herein are based on various formal long term statements of need expressed by the Chief of Naval Operations and the Commandant of the Marine Corps. This document is intended for in-house use by personnel concerned with planning and programming the Exploratory Development Program at all levels of the technical community.

This set of goals is for the Undersea Target and ASW missions.

11. "Goals for Technology in Exploratory Development - The Air Target," Preliminary report published by the Chief of Naval Development (MAT 311), dated 17 November 1965. (SECRET)

Purpose is to assist in formulating the Exploratory Development Program of the Navy. The goals included herein are based on various formal long term statements of need expressed by the Chief of Naval Operations and the Commandant of the Marine Corps. This document is intended for in-house use by personnel concerned with planning and programming the Exploratory Development Program at all levels of the Technical community.

This set of goals is for the anti-air mission and the air target.

12. "Advanced Developments and Advanced Development Candidates for Tactical Missiles and Weapons," PROJECT SMEADO '67, Missile Development Office (RM), Bureau of Naval Weapons, RM-67-1A, June 1965. (SECRET)

Main body, Sections 1 through 9, consists of brief summaries of FY 67 plans for Advanced Developments and Advanced Development Candidates in the Tactical Missiles and Weapons Area. These summaries are abstracts of forty individual current planning documents, prepared under PROJECT SMEADO. Taken together, the forty summaries constitute a SMEADO '67 Catalog for Missile Development Office (RM) operations. Plans for the Missile Flight Evaluation Systems Area are not included.

13. "Navy Program Factors," Office of Chief of Naval Operations, OPNAV 90P-02, Revised May 1965. (CONFIDENTIAL RD)

"Navy Program Factors supplements the Navy Programming Manual (OPNAV 90P-1). It is comprised of Program Factor Description Sheets and Program Factor Data Sheets grouped by the major resource areas of ships and aircraft. The program factors will be used in the Navy planning and programming analytical procedure (Cost Model) for estimating the resource implications (material, personnel, dollars) of various force levels and varying levels of support of these forces.

14. "Project SEABED," Advanced Sea-Based Deterrence Summer Study 1964, Naval Ordnance Laboratory, Silver Spring, Maryland, July 1964. (SECRET RD)

Four-volume report giving the results of the summer study held in Monterey, California, by the Special Projects Office. The four volumes are as follows:

Vol. I - Summary

Vol. II - Contemporary Analysis of Sea-Based Deterrence

Vol. III - Weapons Systems for Sea-Based Deterrence

Vol. IV - Advanced Undersea Technology

15. "Status and Projections of Developments in Hull Structural Materials for Deep Ocean Vehicles and Fixed Bottom Installations," W. S. Pellini, Naval Research Laboratory, Washington, D. C., NRL Report 6167. 4 November 1964. (Unclassified)

    Projects state-of-the-art in materials for deep ocean operation. Used at PROJECT SEABED in defining the potentials for deep-ocean vehicles and installations in the 1980's and the R&D necessary to make these potentials a reality.

16. "Review of Re-entry Body, Penetration Aids and Arming and Fuzing Technology for PROJECT SEABED," R. K. Lobb, Naval Ordnance Laboratory, Silver Spring, Maryland, NOLTR 65-44, 13 March 1965. (SECRET RD)

    Contains a review of knowledge and technology applicable to the design of payloads for future (1970-75) ballistic missiles. Discusses offense-defense tactics, trajectory calculations on ballistic and maneuvering re-entry vehicles, aerodynamics of penetration aids, and arming and fuzing devices.

17. "Appraisal of the Navy Research and Engineering Program 1964-ANREP-64," Prepared by the Technical Analysis and Advisory Group, Office of Deputy Chief of Naval Operations (Development), 3 volumes, dated September 1964. (SECRET—For internal Navy use only.)

    An appraisal of the Navy Research, Development, Test and Evaluation Program. Provides information to support the decision-making exercised by the various managerial levels of the Navy Department. Evaluates the quality of the RDT&E program, using as criteria, the possible contributions toward an improved naval combat capability. Similarly, the adequacy of the statements of operational needs in furnishing guidance to the R&D community is also reviewed.

    This edition of ANREP consists of three volumes. These allow easy reference to different portions of the document, as well as a side-by-side review of summary statements with more detailed information. Volume I, "Summary," contains a section entitled "Highlights" that invites attention to many items of significant information in the appraisal, and separate sections summarizing major findings and recommendations pertaining to System Development and Exploratory Development programs. Volume II, "Exploratory Development Commentary," contains more detailed information on the Exploratory Development programs. Volume III, "Systems Development Commentary," contains more detailed information on advanced, engineering and operational developments.

18. "Index of Navy Development Requirements," DCNO(D), Encl (1) to CNO 0201P70, January 1965. (CONFIDENTIAL)

    Contains: (a) A list of Planning Objectives, General Operational Requirements, Tentative Specific Operational Requirements, Specific Operational Requirements and Advanced Development Objectives (Part I) for use in verifying that requirements files are current; (b) An index of Operational Requirements and Development Characteristics (Part II), which will be phased out as they are replaced by updated GOR's and SOR's.

19. "Department of the Navy RDT&E Management Guide," Vols. I and II, NAVEXOS P-2457, July 1964. (Unclassified)

    Published in two volumes—"Vol. I - Organization and Procedures" and "Vol. II - Appendices." Prepared to aid both newcomers and practicing "journeymen."

20. "The United States and the World in the 1985 Era," Syracuse University Research Corporation (Project 1985), DDC Report AD 613 527 (Annex, AD 613 528), March 1964. (Unclassified)

Prepared in response to request by the Marine Corps to predict what certain aspects of the world would be like in 1985. In the language of the Marine Corps, "This study will examine projected national objectives and policies, and international and domestic military, economic, and technological factors affecting the United States in the 1985 era."

21. "Science and Technology in the 1985 Era," Syracuse University Research Corporation (Project 1985), DDC Report AD 613 525 (Appendix AD 613 526) May 1964. (Unclassified)

Report and its appendix is in support of the reference above. Covers the technological aspects of the projection. Forecasts technology as related to the Marine Corps of the next two decades.

22. "Long Range Technological Forecast," 3rd Edition. Prepared by the Office of the Chief of Research and Development, Department of the Army, 3 Volumes. April 1965 (SECRET RD)

The Army Long Range Technological Forecast (LRTF) is designed to be of value in both technical and operational planning. It covers a period of 20 years.

The Forecast describes knowledge, capabilities, and examples of material which science and technology can be expected to produce if supported by orderly programs of research and development and represents one element of a current and comprehensive plan for long-range technical planning.

Published in 3 volumes, entitled, "Scientific Opportunities," "Technological Capabilities," and "Advanced Systems Concepts."

23. "Forecast in Depth - Information Processing Systems for the Field Army," H. T. Darracott, Technical Forecasting and Objectives Branch, Research and Development Directorate, U. S. Army Materiel Command, Washington, D. C. (Unclassified)

Comprehensive study of the peripheral equipments in an automatic information processing system. Part of its purpose was to provide a tool to aid in the design of such equipment for tactical data processing systems.

24. "The Army Research Plan," Industry Edition, Office of the Chief of Research and Development, Department of the Army, No. ARP-65, dated 1 March 1965. (CONFIDENTIAL)

The Army Research Plan (ARP) is an extension of the Army Research and Development Long Range Plan. Its purpose is to afford guidance to those commanders and agencies responsible for the detailed formulation of the Army's research programs by assigning relative levels of recognition to scientific and technological areas of interest to the Army.

25. "Combat Development Objectives Guide," Combat Development Command, Department of the Army, dated 15 August 1964. (SECRET RD-NOFORN)

The purpose of the Combat Development Objectives Guide is to provide guidance for the development of future operational concepts, organizations and materiel. States general combat development objectives and consolidates the studies, field experiments, and approved qualitative materiel requirements which are pointed toward the attainment of these objectives.

26. "The Army Study System," Director Special Studies, Department of the Army, Office of the Chief of Staff, Washington, D. C. 3 Volumes, dated 18 May 1964. (Official Use Only)

Examines current (1964) Army major study activities and evaluates effectiveness of the studies as inputs to planning, programming, budgeting, and other needs. The three volumes are: Basic Study (Vol. I); Study Documentation and Information Retrieval (Vol. II), and Bibliography of Current Major Army Studies, 1962 to Date (1964) (Vol. III).

27. "The Army Master Study Program 1965," Army Study Advisory Committee, Chief of Staff, Department of the Army, dated 31 [illegible]cember 1964. (CONFIDENTIAL)

The Army Master Study Prog[illegible]m, 1965 is designed to provide:

a. A formal, approved list of those major studies being pursued under the sponsorship of the Army Staff Agencies, Hq., Department of the Army, which are considered to be of prime importance to overall Army planning, force development and programming.

b. A mechanism for the use of the Army Staff to determine gaps or unbalanced emphasis within the overall study effort and thus enable more effective support by studies to the orderly development of the well balanced, multipurpose Army of the future.

c. An orientation of the Army's study processes towards the [illegible] concepts, missions and guidance for the Army of the future which are enu[illegible] in the document "Assessment of the Army, 1964."

d. A useful compendium of major Army study efforts for the information of the Office of the Secretary of Defense and other interested government agencies.

28. "Technology for Tomorrow," 5th Edition 1962-63, Aeronautical Systems Division, AFSC, Wright-Patterson AFB, Ohio, 62ASOP-300, December 1962. (SECRET)

"Technology for Tomorrow" is a presentation of motivational concepts outlining the approach to an optimum plan. It is a guide to the organization and selective application of resources and capabilities for an aggressive support of the long range Air Force technical mission. Thus it represents a step in the planning process. The contents and organization of the document reflect in themselves the fact that a cohesive detailed plan exists collectively in the minds of the engineers, scientists, and management personnel who have contributed to its formulation.

29. "Operations FORECAST," 14 vols., SCGF-46-7, Forecast Special Project Office, Hdq., AFSC, Andrews AFB, Maryland, January 1964. (SECRET)

30. "Project FORECAST," Organization and Mission Planning Group Report dated 13 April 1963. (Unclassified)

Discusses the organization and planned operation of the 1963 study, Project FORECAST, conducted by the Air Force. Explains duties of the individuals and panels and how it was expected the panels would interact.

31. Project Forecast Panel Reports:

a. Navigation and Guidance (AD 354 060)

b. Electronic Countermeasures and Counter Countermeasures (AD 354 062)

c. Intelligence and Reconnaissance (AD 354 063)

d. Communications, Vols. I and II (AD 354 058, AD 354 059)

e. Weapons (AD 354 057)

f. Power Generation (AD 354 053)

g. Flight Dynamics (AD 354 051)

32. "AFSC Technological War Plan." Prepared by Deputy Chief of Staff Plans, AFSC, Washington, D. C., Basic Plan No. TWP Basic SCL-65-3, dated March 1965. (SECRET)

This report is the AFSC Command Plan for the conduct of R&D activity in support of their assigned responsibility.

The TWP consists of a basic plan and five supporting annexes. Purpose of each is briefly stated as follows:

The "Basic Plan" integrates the content of the annexes and provides the transition of planning effort into programs and budgets.

Annex A, "Environment," discusses the broad setting within which the technological threat and our military policy goals are evolved.

Annex B, "Threat," describes the expected evolution of aggressor systems and technology.

Annex C, "Systems," projects and describes concepts and capabilities which may evolve into the systems of the future AF force structure.

Annex D, "Technology," describes technology for deriving system capabilities and projects efforts to strengthen the Command's technological base.

Annex E, "Resources," projects mission man-years, technical facilities and RDT&E funds necessary to develop, test and evaluate both technology and systems.

33. "Technical Objectives Documents," Research and Technology Division, AFSC, 36 Technical Area Reports. November 1965. (Unclassified)

These documents are prepared to provide means of communicating with science and industry, to describe the Air Force's objectives in each of 36 different technical areas. As is the case in any selective grouping of science and technology, it is difficult to draw sharp boundaries between areas and thus overlaps occur.

34. "RTD Technological War Plan/Long Range Plan," Research and Technology Division, AFSC, Washington, D. C. Report No. RTL 64-25 April 1964 and changes. (SECRET)

This Plan describes the future course of action that the Research and Technology Division will take in managing the Air Force Exploratory and Advanced Development Programs. It is prepared by the people most familiar with these programs—the working scientists and engineers in the Air Force Laboratories. It is an attainable Plan; it describes how RTD will allocate those resources which it may realistically expect to have available over the next decade.

The Plan is oriented toward achieving the level of technology required to attain the future Air Force capabilities identified by PROJECT FORECAST. It also recognizes that a major objective of this Division is the building and maintaining in our Laboratories of a strong in-house technical capability.

Changes will undoubtedly alter various parts of this Plan. Breakthroughs will occur and unsuccessful efforts will be terminated. On the whole, however, the Plan represents a coordinated picture of where RTD is going over the next decade, as we now see it.

35. "Office of Aerospace Research - Five-Year Plan," Directorate of Plans, Hq., Office of Aerospace Research, USAF, Washington, dated 1 July 1965. (Unclassified)

The Office of Aerospace Research is responsible for the Air Force research program, together with a small number of exploratory development projects. Since the OAR tasks are generally of a long-term nature, its goals must be forecast against relatively uncertain visions of the future. Nevertheless, in the interest of maximum economy and effectiveness in the use of our national resources, the OAR will proceed along carefully plotted courses of action. This year's FIVE Year Plan sets forth organizational and research objectives for FY 1968 through FY 1970, describes courses of action for their accomplishment, and presents studied estimates of the requisite resources.

36. "Long Range Scientific and Technical Intelligence Assessment (LRTIA) of the USSR," Defense Intelligence Agency, Washington, Report No. ST-CS-17-1-65-INT dated 1 August 1965. (SECRET-NOFORN)

37. "Mirage 75," Military Requirements Analysis Generation 1970-75. H. A. Linstone, Lockheed Aircraft Corporation, Burbank, California, Report No. LAC/592371 dated January 1965. (SECRET RD)

This report is the Lockheed corporate planning study on military requirements. Projects the environment to 1970-75 and forecasts systems and technology to meet the projected environment. A similar study, "Mirage 80," is underway.

38. "U. S. Defense Posture - Overview 1964-1974," Guidance and Control Systems Division, Litton Systems, Inc., Publication No. 3373, OPR64-1, dated June 1964. (Unclassified)

Provides an overview of the economic, political and military context of the defense market over the next ten years. The major environmental conditions that will shape the domestic and international economic and political climate which will prevail during this time period are evaluated in light of their impact on the defense market.

39. "Report on a Long-Range Forecasting Study," T. J. Gordon, O. Helmer, Report P-2982 Rand Corp., Santa Monica, California, September 1964. (Unclassified)

Describes an experimental trend-predicting exercise covering a period extending as far as fifty years into the future. The experiment used a sequence of questionnaires to elicit prediction from individual experts in six broad areas: scientific breakthroughs; population growth; automation; space progress; probability and prevention of war, and future weapon systems.

40. "The World of 1975," Stanford Research Institute (Composite of following SRI Reports: 232, 233, 234, 235, 236). No date. (Unclassified)

Composite of reports on forecasts by SRI Long Range Planning Service in predicting the world of 1975. Includes the following subjects:

a. The International Prospect,

b. Economic Trends,

c. Governmental and Political Trends,

d. Science and Technology, and

e. Social and Cultural Framework.

41. "Project PATTERN-Planning Assistance through Technical Evaluation of Relevance Numbers," paper presented by A. L. Jestice, Military and Space Sciences Department, Honeywell, Inc., Washington, D. C., to Operations Research Society of America, October 7-8-9, 1964. (Unclassified)

Discusses a method of evaluating and determining how to structure a research and development program. The method is intended to be an aid to management in planning.

42. "A Feasibility Study of Techniques for Measuring and Predicting the State-of-the-Art," F. L. Bagby, et al., Battelle Memorial Institute, Columbus, Ohio. DDC Report (AD 233 350). July 1959. (Unclassified)

Discusses the results of a feasibility study on techniques for measuring and predicting the state-of-the-art. The method used relied heavily on case histories in system development. The study was conducted for the Air Force.

43. "The Role of the Federal Government in Technological Forecasting," D. Schon, et al., Interagency Task Group on Technological Forecasting in Federal Government. January 1966 (Unclassified)

A report to the President's Committee on Manpower and to the National Commission on Technology, Automation and Economic Progress. Specifically, the investigation focused on:

a. Action points in government at which technological forecasting might be useful and used, if available;

b. Criteria for information at these action points;

c. Current technological forecasting activities and methodologies and their adequacy to Federal requirements.

44. "PROFILE - Programmed Functional Indices for Laboratory Evaluation," M. J. Cetron, Advanced Concepts Branch, Headquarters, Naval Material Command, Washington, D. C. Paper presented at the 16th Military Operations Research Symposium, 12 October 1965. (Unclassified)

The design objectives of this program are to develop a methodology for project evaluation. At the time of this writing PROFILE is undergoing rigorous tests of its discriminative characteristics. However, the results of the study to date show internal consistency, and indicate that such a system of evaluation may be of potential value to laboratory management. PROFILE is designed to help top management objectively select tasks and appraise the total laboratory R&D program; it will appraise the value of each laboratory task objective, it will make available a task PROFILE showing where each task is strong, and it will give top management a means of explaining to various groups the tool which is used in generating and appraising the total laboratory's program.

45. "A Systems Development Planning Structure," An interim report by ABT Associates, Inc., 14 Concord Lane, Cambridge, Massachusetts, to Hq., Air Force Systems Command (SCLS), Andrews Air Force Base, Washington, D. C., 18 November 1965. (Unclassified)

In the development of systems, this computerized technique is intended to provide the decision-maker with an estimate of the implications of his placing special emphasis on particular policies by describing possible situations related to each policy. It is designed to assist with the assignment of a consistent set of relative values to any number of objectives by eliciting "Yes" or "No" responses from the decision-maker to questions about preferences for various combinations of objectives.

46. "An Approach to Research and Development Effectiveness," paper presented by A. B. Nutt, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio, to 17th NAECON Conference Proceedings, 12 May 1965. (Unclassified)

This paper describes the rationale and use of RDE (Research and Development Effectiveness); a computerized planning program developed in-house and designed to utilize analytical techniques in the management of R&D resources in the Air Force Flight Dynamics Laboratory, RTD, AFSC.

47. "The QMDO Planning Process as it Relates to the U. S. Army Materiel Command," Cornell Aeronautical Laboratory, Inc. Prepared for U. S. Army Materiel Command, Contract No. DA-49-186 AMC-237(X), 31 August 1965, CAL No. VQ-2044-H-1.

The operational aspects of the QMDO (Qualitative Materiel Development Objectives) planning process are investigated and defined with respect to generating a DA-Approved QMDO, producing a QMDO Plan and analysis and synthesis of management information at Headquarters, AMC. A mathematical choice model is developed to assist management at AMC Headquarters in the synthesis of information for the purpose of determining which QMDO related Research and Development Tasks to fund. This model is adopted from the analytical method suggested in Cornell Aeronautical Laboratory Report No. VQ-1887-H-1, 19 May 1964, "An Analytical Method to Aid in the Choice of Long Range Study Tasks," using structural elements and constraints applicable to the QMDO problem. The mathematical description of the revised choice model and new programming specifications in the form of flow chart. are included in an appendix. Also shown in an appendix, are sample numerical outputs of choice configurations for various QMDO constraints, obtained by making use of hypothetical input data similar to those used in the previous work. Finally, based on the planning process investigations and proposed choice model, a draft of a pamphlet which would be useful in implementing the suggested program is developed and included.

48. "The LRTP Planning Process as it Relates to the U. S. Army Materiel Command," Cornell Aeronautical Laboratory, Inc. Prepared for U. S. Army Materiel Command, Contract No. DA-49-186 AMC-237(X), 30 October 1965, CAL No. VQ-2044-H-2.

The research and development program structure is investigated to identify factors relevant to the structure of the AMC Long Range Technical Planning process. The results of the investigation are used to structure a proposed planning process for AMC. An analytical choice model is developed to aid Management at Headquarters AMC in the synthesis of information generated by the planning process for the purpose of determining which LRTP tasks to recommend for funding. The resulting model is programmed for operation on an IBM 7090 digital computer.

A detailed description of the mathematical model and computer program is not included in this report, but is given in a separate report (Cornell Aeronautical Laboratory Report No. VQ-2044-H-3, "LRTP Mathematical Model Brochure").

49. "LRTP Mathematical Model Brochure," Cornell Aeronautical Laboratory, Inc. Prepared for U. S. Army Materiel Command, Contract No. DA-49-186 AMC-237(X), 30 October 1965, CAL No. VQ-2044-H-3.

This brochure contains a technical description of the LRTP Choice Model derived in Cornell Aeronautical Report No. VQ-2044-H-2, "The LRTP Process as it Relates to the U. S. Army Materiel Command." The brochure is self-contained in that the technical aspects may be read and understood without referring to the above report.

This brochure includes a mathematical description of the model; a description of the computer program which includes flow charts, a FORTRAN listing and a debugging log; several numerical examples of program outputs using hypothetical input data.

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13. ABSTRACT

Part 1, Summary Report, presents in concise form the results of a six month study carried out by the Navy Technological Forecasting Study Group. The preparation of a Navy Technological Forecast is recommended, the nature and utility of such an effort are described, and a procedure for its accomplishment is briefly presented.

Part 2, Back-Up Report, presents much detailed su[illegible]rting material, sample forecasts, methodologies, and possible ca[illegible]gories It is expected that the details covered will greatly aid those responsible for generating Navy Technological Forecasts

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